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New Zealand Fisheries Assessment Report 2005/38
July 2005

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CONTENTS

EXECUTIVE SUMMARY 5

1. INTRODUCTION 6

2. ASSESSMENT MODEL 7

  2.1 Model fitting 7
  2.2 Markov chain-Monte Carlo simulations 8
  2.3 Projections 8
  2.4 Fishery indicators 8
  2.5 Sensitivity trials 9
    2.5.1 MPD sensitivity trials 9
    2.5.2 McMC sensitivity trials 9
  2.6 Retrospective analysis 10

3. ASSESSMENT MODEL INPUTS 10

  3.1 Fishing years and seasons 10
  3.2 Structure of size frequency data 10
  3.3 Control variables 10
    3.3.1 Catches 10
    3.3.2 Regulation history 12
  3.4 State variables 13
    3.4.1 Biomass indices 13
    3.4.2 Proportions-at-size 14
    3.4.3 Parameter priors 15
  3.5 Other values 15
  3.6 Development of a base case 15

4. ASSESSMENT RESULTS 16

  4.1 Base case MPD estimates 16
    4.1.1 Fits to data 16
    4.1.2 MPD Trajectories 17
    4.1.3 MPD sensitivity trials with the CRA 3 base case 18
  4.2 McMC simulations and Bayesian results 18
    4.2.1 Fits to data 18
    4.2.2 Posterior trajectories 19
  4.3 Summary of the CRA 3 assessment 19
  4.4 MCMC sensitivities 20
  4.5 MCMC retrospectives 21
  4.6 Additional projections 21

5. DISCUSSION 21

  5.1 Model and data 21
  5.2 Model behaviour 22
  5.3 CRA 3 assessment 23

6. ACKNOWLEDGEMENTS 23

7. REFERENCES 23

APPENDIX A. ASSESSMENT MODEL 107

  A.1 Initial size structure 110
  A.2 Overview of dynamics 110
  A.3 Selectivity and relative vulnerability 111
  A.4 Vulnerable biomass 111
  A.5 Exploitation rates 112
  A.6 Fishing mortality 113

A.7 Natural mortality 113
A.8 Growth........ 114
A.9 Recruitment 115
A.10 Maturation 116
A.11 Predictions and likelihoods for abundance indices 116
A.12 Predictions and likelihood for proportion-at-size 118
A.13 Likelihood of tag size increments 119
A.14 Likelihood of recruitment residuals........ 120
A.15 Surplus production 120

APPENDIX B. DATA USED IN THE ASSESSMENT........ 121

EXECUTIVE SUMMARY

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***New Zealand Fisheries Assessment Report* 2005/38. 126 p.**

We used a length-based model to assess the CRA 3 stock of rock lobster (*Jasus edwardsii*). The model simulates recruitment, growth, natural mortality and fishing mortality in 6-month periods from 1945. The fishing model includes differential vulnerability for males, immature females and mature females based on size and season. The model was revised to address the effect of Te Tapuwae o Rongokako Marine Reserve, established in area 909 of CRA 3 in November 1999. The effect modelled was a 10% removal of the available stock in 1999 and a 10% reduction in recruitment to the available stock after 1999.

The model is driven by estimated catches (commercial, recreational, illegal and Maori customary) and is fitted to relative abundance, proportion-at-length and tag-recapture data from the CRA 3 fishery.

The assessment was based on Bayesian techniques. Markov chain-Monte Carlo (McMC) simulations were used to estimate the marginal posterior distributions of parameters and indicators. The modes of joint posterior distributions were used to evaluate some sensitivity trials and a retrospective analysis. More important sensitivity trials were based on McMC simulations. These trials suggested that total uncertainty is much higher than the base case McMC results would suggest.

For CRA 3, the current vulnerable biomass is lower than the target reference biomass level, *Bref*, but is higher than the limit reference biomass, *Bmin*. Projections were highly uncertain. Under the assumptions of the projections – constant catches at the 2003 levels, constant seasonal distributions of catches at the current levels and recruitments resampled from the past decade – biomass is slightly more likely than not to increase from the current level, will probably remain above *Bmin*, but will very likely remain below *Bref*.

Additional projections were made with alternative catch assumptions at the request of the National Rock Lobster Management Group, and these results are also presented.

1. INTRODUCTION

The spiny lobster *Jasus edwardsii* supports the most valuable inshore fishery in New Zealand, with annual exports worth over $100 million. For a literature review of New Zealand *J. edwardsii*, see Breen & McKoy (1988); for fishery descriptions see Annala (1983) and Booth & Breen (1994); for recent management details see Sullivan (2004) and Booth et al. (1994). Recent assessments were described by Bentley et al. (2001), Breen et al. (2002), Starr et al. (2003) and Kim et al. (2004).

The commercial fishery (an inshore trap or pot fishery in the areas described here) has been managed since 1990 with a system of individual transferable quotas (ITQs). Before quotas were introduced in 1990, the fishery was managed with limited entry and by input controls. These included minimum legal sizes (MLS), recreational bag limits, protection of ovigerous females and soft-shelled lobsters, and some local spatial and seasonal restrictions. In 1990, the fishery was brought into the Quota Management System (QMS), but the input controls were retained. Ten Quota Management Areas (QMAs), each with a separate Total Allowable Commercial Catch (TACC), were put in place in 1990. The revision to the Fisheries Act in 1996 also requires the Minister to set a Total Allowable Catch (TAC) which includes all known sources of fishing mortality including commercial catch, recreational catch, Maori customary catch, illegal catch and fishing-related mortality.

The Fisheries Act 1996 requires that New Zealand fishery stocks be managed so that stocks are maintained at or above B_{MSY}, the biomass associated with the maximum sustainable yield (*MSY*). However, B_{MSY} is not defined by the legislation, B_{MSY} is not a single value but may vary because of natural fluctuations in biomass, and *MSY* can be defined only in association with a specific harvest strategy (Francis 1999). The Ministry of Fisheries (MFish) and the National Rock Lobster Management Group (NRLMG) annually advise the Minister of Fisheries whether stocks are at or above a target reference point, *Bref*, that serves as a proxy for B_{MSY}, and whether current TACs and TACCs are sustainable and likely to move stocks towards *Bref*. A limit reference point, *Bmin*, is also used. The work described here was conducted by fisheries scientists under contract to the New Zealand Rock Lobster Industry Council (NZRLIC), which was contracted by MFish to provide an assessment for the CRA 3 (Gisborne) fishstock. Conduct of the work throughout was described to and discussed by the Rock Lobster Fishery Assessment Working Group (RLFAWG) (below called the "Working Group"), comprising representatives from MFish and all stakeholder groups.

Length-based models of the type described by Punt & Kennedy (1997) have been used since 1998 to assess rock lobsters in New Zealand. For fished populations that cannot be aged, length-based models are becoming widely used. The model used here models growth with a transition matrix that has no reference to "age" except at the recruitment phase. In this structure it is comparable with the approach of Bergh & Johnston (1992) for South African rock lobsters (*Jasus lalandii*), Sullivan et al. (1990) for Pacific cod (*Gadus macrocephalus*), Zheng et al. (1995) for Alaskan king crabs (*Paralithodes camtschaticus*) and Breen et al. (2003) for the New Zealand abalone *Haliotis iris*. The heart of such models is a stochastic growth transition matrix that calculates the probabilities that animals of a given length will grow into a vector of possible future lengths.

The specific model used in this study was first written for the 1999 assessment and revised for the 2000 assessment as described by Bentley et al. (2001), for the 2001 assessment after an extensive review (Breen et al. 2002), for the 2002 assessment of CRA 1 and CRA 2 (Starr et al. 2003) and for the 2003 assessment of CRA 4 and CRA 5 stock (Kim et al. 2004). Revisions to dynamics were made for this study as described below.

The assessment uses Bayesian techniques to estimate uncertainty in the assessment (see Punt & Hilborn (1997) for a discussion of Bayesian techniques and their use in fisheries stock assessments). These techniques are becoming standard tools in this field (e.g., McAllister et al. 1994, Meyer & Millar 1999).

The model is fitted to five data sets: standardised catch per unit effort (CPUE), historical catch rates (CR), pre-recruit indices from catch sampling and voluntary logbooks, proportions-at-size from catch sampling and voluntary logbooks, and growth increments from tag-recaptures.

This report describes the revised size-based model, describes and lists the data used for the CRA 3 assessment and presents and discusses the assessment results.

2. ASSESSMENT MODEL

Two seasons are defined: "autumn-winter" (AW) from 1 April through 30 September and "spring-summer" (SS) from 1 October through 31 March.

The 2004 assessment of CRA 3 used a revision of the model described by Kim et al. (2004). Full model details are provided in Appendix A. Main changes made to the model involved addressing a new marine reserve in CRA 3, where no fishing is permitted.

The Te Tapuwae o Rongokako Marine Reserve was established in area 909 of CRA 3 in November 1999. The fishing industry claimed that it displaced 10% of their former fishing area, a claim not seriously disputed in the Working Group, which oversaw the assessment. In addressing the reserve, the Working Group discussed three possible effects of the marine reserve:

- a stock-recruit effect, through which increased egg production in the reserve might lead to increased recruitment in CRA 3,
- a yield-per-recruit effect, through which the partial refuge and interchange of animals between the fished stock and the marine reserve could increase yield-per- recruit and
- removal from the fishery of a portion of the stock and the ground it occupies.

The Working Group saw no basis for modelling hypothesis a) given the wide dispersal of larvae and the small area of the reserve relative to the areas of settlement. The Working Group noted that b) implicitly assumes growth over-fishing and assumes that significant interchange of lobsters occurs between the remaining fished stock and the new reserve. There is no evidence for the first assumption and movement data collected by DoC (D. Freeman, DoC, pers. comm.) do not support the second. The Working Group agreed to implement the third effect, which is the simplest of the three hypotheses and possibly the most conservative, by removing an agreed percentage (10%) of the stock from the fishery in 1999 and assuming that recruitment to the model drops by that same percentage in subsequent years. Effectively, this hypothesis assumes that the stock has become smaller as a result of establishing the marine reserve.

The total fishery comprises four elements that the model condenses to two. The commercial and recreational sectors are governed by the MLS and restrictions on landing berried females, and together these are called the SL fishery and the catch is called the SL catch or C^{SL}. The Maori customary and illegal fisheries are not bound by those regulations and together are called the NSL fishery and the catch is called the NSL catch or C^{NSL}.

The model is implemented in AD Model Builder™ (http://otter-rsch.com/admodel.htm).

2.1 Model fitting

Model parameters are estimated by minimising a total negative log-likelihood function, which is the sum of the negative log-likelihood components from each data set, the negative log of the prior probabilities of estimated parameter values, and penalty functions.

For each data element in each data set, the standard deviation of a common error component used in the likelihood component, $\sigma_{j,k}$, is calculated as

$$\sigma_{j,k} = \tilde{\sigma}\sigma'_j / \varpi_k$$

where j indexes the elements within a data set and k indexes data sets, $\tilde{\sigma}$ is the component common to all data sets and estimated by the model, σ'_j is the standard deviation associated with the jth element of the data set and ϖ_k is the relative weight assigned to the data set.

Likelihood of the fit between observed and predicted proportions-at-size, normalised across males, immature females and mature females, is calculated assuming that proportions are normally distributed and have standard deviations that give most weight to the larger proportions and least to the smallest (Eq 41 in Appendix A). This reflects a belief that small proportions are most likely to be affected by sampling biases and random errors.

Recruitment deviations were estimated for every year from 1945 through 2000. The 2000 annual deviation was applied to year 2001 through 2003 in the minimisation and McMC phases; in the projection phase, deviations for 2000 through 2008 were obtained from resampling.

2.2 Markov chain-Monte Carlo simulations

After obtaining the best fit, which is the mode of the joint posterior distribution (MPD), by minimising the total function value, we used Bayesian estimation procedures to estimate uncertainty in model parameters, quantities and projected quantities. Posterior distributions for parameters and quantities of interest were estimated using a Markov chain-Monte Carlo procedure (McMC) implemented in AD Model Builder through the Hastings-Metropolis algorithm. The posteriors were based on 7505 samples selected from one chain of 15 million simulations. The chain was started from the MPD.

2.3 Projections

From each of the posterior samples for each area, we made 3-year projections of biomass, encompassing the 2004–05 through 2006–07 fishing years, under the assumptions that commercial catches would equal the 2003 level, that other catches would remain at their 2003 levels during the projection and that the seasonal split of catches remained as in 2003. These were 226 t and 110 t for the SL and NSL catches respectively. Projected recruitments for the years 2000–03 were randomly resampled from the estimated model recruitments from the period 1991–2000.

After the assessment had been reported to the Plenary, the NRLMG requested additional projections with other assumed catch levels, and these are also described below.

2.4 Fishery indicators

The assessment used several performance indicators based on biomass, all using "index biomass": the mid-season biomass (after removal of half the catch) legally available and vulnerable to the fishery (e.g., above MLS and non-berried females) in the AW season. The stock was estimated to be at its lowest level in 1992, so the minimum biomass indicator, *Bmin*, is taken from the AW season of 1992. Current biomass, *Bcurr*, is taken from the AW season of 2004. Projected biomass, *Bproj*, is taken from the AW season of 2007.

In recent years we have defined and used biomass in a reference period and treated this as a reference level and a proxy for B_{MSY}. This was a level with a demonstrable degree of productivity and safety based on the fishery history. The choice of reference period is perforce arbitrary and open to debate. In 2004 the industry in CRA 3 agreed on a target CPUE for the fishery of 0.75 kg/potlift. They considered this was a desirable catch rate for the fishery, and shelved quota in 2004–05 to start the rebuild of biomass and catch rates to this higher level.

For this assessment a new reference biomass *Bref* is defined: it is the biomass associated with a CPUE of 0.75 kg/potlift. This catch rate occurs at a higher biomass than the previously agreed reference biomass. The Working Group accepted this new reference level as an appropriate short-term target for the fishery and noted the lower associated risks inherent in this choice. The equivalent mean CPUE for 1974–79 (the previously used reference period) was about 0.57 kg/potlift. The reference biomass associated with the target CPUE is calculated simply from the estimated proportionality constant for CPUE.

Four exploitation rate indicators are the recent (AW 2003) and projected (AW 2006) exploitation rates on the sectors of the population that support the SL and NSL catches.

Two additional indicators are the percentage of runs for which *Bproj* exceed *Bcurr* after the three-year projection and the percentage in which *Bproj* was less than *Bmin*.

2.5 Sensitivity trials

2.5.1 MPD sensitivity trials

Sensitivity of the MPD results was examined to see which, if any, data sets were inconsistent with other data sets and to explore the effects of choices made during the process of finding a base case. We ran sensitivity trials, obtaining alternative MPD results, by removing the five data sets – CPUE, CR, PRI, tags and proportions-at-length – one at a time; we set the maximum exploitation rate to 0.8 and 0.9 (0.95 was assumed in the base case); we changed the assumption that the most vulnerable lobster were males in SS to males in AW; we fitted to an alternative catch series where the non-commercial catches were doubled and we estimated a power function in the CPUE-biomass relation.

2.5.2 McMC sensitivity trials

We ran four MCMC sensitivity trials:

- a "fixed growth" trial with growth parameters fixed at values obtained by fitting only to the combined base case tagging data from both CRA 3 and CRA 5 (10 million McMC simulations),
- another fixed growth trial, "fixed growth A3", with growth parameters fixed at values obtained from fitting only to the CRA 3 tagging data (1 million McMC simulations),
- a trial called "free *M*", with an increased upper bound on *M* and with an increased c.v. of the prior on *M*, both of which allowed *M* to be estimated at a high value (1 million McMC simulations) and
- a "domed" selectivity run with the right hand limb parameter fixed to 20 (based on a trial estimation run), which allows the model to create cryptic large lobsters (1 million McMC simulations).

These trials addressed the main areas where the modellers thought modelling choices may have been influencing the base case: growth parameter estimates were obviously central to the model's other estimates; we were reluctant, in finding a base case, to accept high *M*; and we considered that using a dome-shaped selectivity curve is unsafe without external corroboration.

In addition, we made 1 million McMC simulations to explore the effects of model structure and priors. For this trial there was almost no weight on the data: all contributions from the data to the objective function were multiplied by a very small number. This was called the "implicit prior" trial.

2.6 Retrospective analysis

Retrospective analysis is a way of testing the predictive ability of a model/data combination. Prediction is the only scientific test of a model, but true predictive testing would take years, in which time both technology and statistical state-of-the-art would have moved ahead to make the model obsolete. A common approach (National Research Council 1998) is retrospective analysis, in which the model's estimates are tested by removing data from one year a time. If the model's biomass trajectory is sensitive to this, then the model's predictive power is suspect.

We conducted one retrospective analysis using a full set of McMC simulations as described for the base case, in which we removed the CPUE and proportions-at-length data from the years 2002 and 2003. Tagging data were not removed: most of the tag-recapture data are from before this period.

In comparing the results, we compared *Bmin*, *Bref* and the index biomass estimated for AW 2001, a point common to both analyses.

3. ASSESSMENT MODEL INPUTS

A summary of data and data sources used in the CRA 3 stock assessments is given in Table 1. A discussion of these data and their sources follows.

3.1 Fishing years and seasons

The model simulation begins in 1945, the first year for which catch data are available. Until 1979, catch data were collated by calendar year. From 1979, catch, catch rate and size frequency data are summarised by fishing year, spanning the period 1 April through 31 March. Fishing years are labelled using the first calendar year in each pair (for example, the 1996–97 assessment year which covers the period 1 April 1996 through 31 March 1997 is labelled "1996").

3.2 Structure of size frequency data

Tail width size frequency data from research sampling and voluntary logbooks were binned separately into 2-mm size classes from 30 to 92 mm. These limits spanned the size range of most lobsters caught in the catch. These bins were considered small enough to provide good resolution in the model without being affected by measurement error.

3.3 Control variables

The catch data, the CPUE abundance indices and other annual and seasonal information used in the assessment are provided in Appendix B.

3.3.1 Catches

The assessment model uses annual values of the SL catch (taken under the MLS and protection of berried females) and the NSL catch (taken without reference to those rules). Four types of catch were considered when collating SL and NSL catch totals by season.

3.3.1.1 Reported commercial catch

Before 1978, the fishing year was the same as the calendar year; the fishing year changed in 1978 to an April through March year. Reported annual commercial catches from 1945 through 1978, summarised by calendar year, were obtained from Annala & Esterman (1986). From 1 January 1979 through 31 March 1986, catches were taken from monthly data compiled by fishing year from data collected by the Fisheries Statistics Unit (FSU), a version of which is now held by the Ministry of Fisheries. The three months of catch from January through March 1979 were added to the 1978 annual total to ensure that no catch was lost when switching from the calendar to fishing year basis for 1979. From 1 April 1986 through 30 March 1988, monthly reported catch totals for all of New Zealand were obtained from Quota Management Returns (QMRs) maintained by the Ministry of Fisheries. These total catches were divided into QMA catches based on landings reported on FSU forms. From 1 April 1988 through 30 September 2001, catches were summarised from monthly returns from QMRs which are available for each QMA. The QMRs were replaced by Monthly Harvest Returns (MHRs) on 1 October 2001, but the same information is used from these new forms.

To divide commercial catch data into seasonal periods for each area from 1 April 1979 to the present, we applied the seasonal proportions from the FSU and Catch Effort Landing Returns data (CELR: held by the Ministry of Fisheries) to the reported catches by fishing year. For 1973 through 1978, seasonal catch data were not available, and the mean seasonal proportions from 1 April 1971 through 31 March 1973 and 1 April 1979 through 31 March 1982 were applied. Monthly catch data from 1 January 1963 through 31 December 1973 (Annala & King 1983) were used to calculate seasonal proportions for 1 April 1963 through 31 March 1973. For the pre-1963 seasonal proportions, the mean seasonal proportions for 1 April 1963 through 31 March 1966 were applied.

Very high commercial catches were taken in the early to mid-1980s (see Figure 1). The FSU system was operating then and we have reasonable confidence in the estimates. Historical annual catch data (John Annala, MFish, unpublished data) for CRA 3 were compared with the catch data used as input for CRA 3, based on the data available in the CRACE database maintained by Trophia and Starrfish. These were similar except for 1961, 1963 through 1973, and 1977. For 1963–73 the catches in CRACE are based on a detailed reconstruction of the Annala & King (1983) data set and considered reliable. Differences observed in 1961 and 1977 are reasonably large but it is unclear which data set would be more accurate. The stock assessment team decided to use data from CRACE because they are based on published information from Annala & King (1983) and Annala & Esterman (1986).

These catches were all assigned to the SL catch, C^{SL}.

3.3.1.2 Recreational catch

The Working Group decided to adopt a catch estimate of 20 t for the CRA 3 recreational catch for all years. This is the Minister's allowance in the CRA 3 TAC.

3.3.1.3 Maori customary catch

The Working Group agreed to use a constant estimate of annual catch of 20 t for the entire assessment period. This is the Minister's allowance in the CRA 3 TAC.

3.3.1.4 Illegal catch

Illegal catch estimates are based on a belief that a large amount of unreported catch was taken before the introduction of lobsters to the QMS. Anecdotal evidence suggests that there were many cash sales and a substantial amount of unaccounted exports of lobster. The factors that contributed to the high level of non-reporting for lobsters are thought to have been reduced after the MLS was changed from tail length to tail width in 1988 and the introduction of lobsters to the QMS in 1990.

The stock assessment team corresponded with Aoife Martin of MFish Compliance (the correspondence was reviewed by the Working Group), who provided updated estimates of illegal catch in CRA 3 for the past decade (see Table 2). These estimates were provided in four categories by year, although all categories have missing estimates for some years: these were treated as zeroes by MFish Compliance and we followed this. The Compliance category "illegal commercial take" (see Table 2) is equated with the category of "commercial illegal reported" used in previous rock lobster assessments. This category is assumed to represent illegal commercial catch reported to the QMS as legitimate catch (undersized, out-of-season and scrubbed females), and is subtracted from reported commercial catch to avoid double-counting.

We calculated the mean ratio of export discrepancies to the reported catch for 1974 through 1980 (Breen 1991). This ratio provides our best estimate of non-reporting for the early years, before compliance estimates. We applied this ratio to the reported commercial catch for 1945 through 1989. MFish Compliance estimates of illegal catch for 1979 and 1987 are of uncertain provenance.

Beginning with 1990, we used the MFish Compliance illegal estimates (see Table 2). Illegal catch for years without Compliance estimates were interpolated as in previous assessments. Two Compliance estimates of "commercial reported" illegal catch, less than 10%, were used to split the illegal catch into reported and unreported illegal catches. We applied this percentage to the whole series of illegal catch estimates.

Illegal catches were divided between seasons in the same proportion as the commercial catch for each year. The reported and unreported illegal catches were both assigned to the NSL catch category, C^{NSL}, and the reported illegal catches were subtracted from the SL catch category, C^{SL}.

Working Group members acknowledged the effort expended by MFish on the illegal catch estimates this year, but continue to have little confidence in the estimates. The estimates cannot be verified and have an associated low level of confidence.

The assumed reported and unreported illegal catch trajectory is shown in Figure 1. SL and NSL catches are shown by season in Tables B1 and Table B3 in Appendix B; the data are plotted in Figure 2. During the first few years' SS seasons, there were no NSL catches because there was no size limit at that time (but in the AW season, mature females cannot legally be taken in June, July and August).

3.3.2 Regulation history

3.3.2.1 Conversion of total length and tail width regulations

Conversion formulae were used to convert MLS regulations and historical data to tail width measurements. Sorenson (1970) provided conversion factors for total length to tail length in inches. Breen et al. (1988) provided conversion factors for tail length to tail width, and conversion factors for carapace length to tail width were obtained from the same study (Breen, unpub. data).

3.3.2.2 MLS regulation history

Annala (1983) provided an overall summary of regulations in the New Zealand rock lobster fishery to 1982, including the timing of MLS changes. Booth et al. (1994) summarised changes after 1983. These regulations are summarised in Table 3; MLS by period, as used by the model, is shown in Appendix B.

3.3.2.3 Escape gaps

Before June 1970, escape gaps were not required (Annala 1983). Street (1973) discussed the introduction of escape gaps but concluded, on the basis of limited sampling, that they were not effective. Escape gap size from June 1970 was set at 54 by 305 mm except in Otago (Annala 1983). Escape gap regulations were changed again in July 1993. We fitted separate selectivity functions for two epochs: 1945 through 1992 and 1993 to the present.

3.3.2.4 Prohibition on the taking of berried females

From 1945 to the present, taking berried females was allowed only in 1950 and 1951 (Annala 1983). This is so short a period that the different regulation for these two years was not addressed in the model.

3.4 State variables

3.4.1 Biomass indices

CPUE from the commercial fishery is used as an index of biomass available to the commercial fishery. Two sources of catch and effort data were available for CRA 3: catch and the number of potlifts from the FSU and CELR databases held by the Ministry of Fisheries (referred to as "CPUE"), and catch and the number of days fished summarised by Annala & King (1983) (referred to as "CR").

3.4.1.1 FSU and CELR data

For CRA 3, standardised abundance indices were estimated from catch per potlift from statistical areas 909, 910 and 911 in the FSU and CELR databases. Relative catch rate indices are obtained by standardising for month and statistical area effects (Maunder & Starr 1995, Breen & Kendrick 1998).

Abundance indices were scaled relative to the first period in the series, and the months which define each season were treated independently. The month with the lowest standard deviation in each season was selected as the base month. The coefficients for the categorical variables (including the abundance indices) are presented as "canonical" indices to remove the dependence on the reference coefficient, with each coefficient calculated relative to the geometric mean ($\tilde{y}$) of the series. This procedure allows the calculation of a standard error for each coefficient, rather than the more usual procedure of leaving the base coefficient with no standard error and apportioning the error associated with the base coefficient to the other indices.

These indices are shown in Appendix B and in Figure 3.

3.4.1.2 Historical data

Monthly catch and effort (days fishing) data from 1963 through 1973 were summarised by Annala & King (1983). These data set were used to calculate catch per day for each season from 1 April 1963 to 31 March 1973 including Gisborne (former statistical area 5) and one-half of Napier (former statistical area 6). These results are reported in Appendix B and shown in Figure 4.

3.4.1.3 Pre-recruit indices (PRI)

Data from the voluntary logbook and observer catch sampling data sets were summarised for each potlift to provide the number of lobsters below the relevant MLS. Berried females were treated as being above the size limit. Only data from 1993 onwards were used because the 1993 change in escape gap regulations made earlier data incomparable with the later data.

The standardisation model used depth (treated as a categorical variable in 20 m bins), statistical area, month, season, year and source of the data (logbook or catch sampling) as explanatory variables. As for the CPUE analysis, a lognormal model that regressed the logarithm of pre-recruit numbers against the five available explanatory variables was fitted for the non-zero data observations. Preliminary explorations using a binomial model were presented to the Working Group, but the results were little different from the lognormal model alone (see Figure 5). Because of problems associated with the zero data, we abandoned fitting to them. Results are reported in Appendix B and in Figure 5.

3.4.2 Proportions-at-size

3.4.2.1 Structure of length frequency data

Tail width frequency data from research catch sampling and voluntary logbooks were binned separately into 2-mm size classes from 30 to 92 mm. These limits span the size range of most lobsters caught. Logbook volunteers measure lobsters with a precision of 1.0 mm while the research sampling precision is 0.1 mm. The measuring convention is to round down all measured lengths, so 0.5 mm was added to each voluntary logbook measurement before binning to avoid introducing bias to the calculated proportions-at-size.

3.4.2.2 Recent data

Proportions-at-size estimates from the commercial catch were obtained from data summarised for the research sampling and logbooks separately, aggregated in area by month cells. Data were then combined for each sample type (observer or voluntary logbook) for 6-month periods (the AW or SS season). In combining the area by month cells, data were weighted by the relative proportion of the total seasonal commercial catch taken in each cell, the number of days sampled and the number of lobsters measured. The weight given to each record was based on the sum of these weights.

3.4.2.3 Historical data

In 2001, CRA 3 market sampling data from the 1970s and 1980s were found (D. Banks, NIWA [now with SeaFIC], pers. comm.) and the model was modified to fit them (Breen et al. 2002). Carapace length measurements were converted to tail width using sex- and area-specific regressions developed by Breen et al. (1988). Data from the first size class above MLS were discarded to reduce the effect caused by morphological variation in carapace length vs tail width near the MLS.

3.4.2.4 Tag-recapture data

The main sources of tag-recapture data are NZRLIC tag-recapture experiments (K. George, NIWA [now with MFish], pers. comm.) and older sets of data in the MFish historical database, for which measurements of carapace length were converted to tail width (Breen et al. 2002).

Tag recovery data were handled as follows.

- For the NZRLIC tag recoveries, multiple recaptures were treated as separate and independent release and recovery events.
- Records were excluded if dates were missing, size at release or recapture was missing, or sex recorded at capture and recapture were different.
- Records were automatically excluded if the apparent increment was less than -10 mm, but records with smaller negative increments were retained, at least in preliminary runs (some were then discarded in outlier analyses).

- Recaptures made in the same period as release were excluded. These may be useful in estimating the observation error of the growth increment, but this parameter is confounded with other estimated growth parameters, and preliminary trials made with only the tagging data suggested this parameter could be fixed.
- A series of preliminary fits were made and records that produced large normalised residuals were examined and discarded, especially if large negative increments were involved.

Each recovery event was summarised in the data file by sex, release and recovery periods, and release and recovery tail widths.

Because the number of recaptures of larger lobsters (larger than 65 mm) from CRA 3 was very small, after preliminary trials we included CRA 5 tag-recapture data in the CRA 3 analyses. When growth for the sizes for which the data series overlapped was compared, CRA 2 tag-recapture data showed different growth from the CRA 3 tag-recapture data. CRA 4 tag-recapture data were insufficient to consider using in the CRA 3 model. For the size range where CRA 3 and CRA 5 growth data overlapped, these two areas showed similar growth rates, and we combined half the CRA 5 data (randomly chosen, to avoid swamping the CRA 3 data) with CRA 3.

A summary of the data by sex and source is shown in Table 4. Tag-recapture data used in the assessment are shown in Figure 6 and Figure 7 for males and females.

3.4.3 Parameter priors

For all estimated parameters, prior probability distributions ("priors") were assumed after discussions in the Working Group (see Table 5). The basis for each non-uniform prior distribution is outlined below.

An informative prior for *M* (log normal prior with mean 0.12 and standard deviation of 0.1) was based on estimated *M* from published studies of temperate lobsters. The standard deviation (0.1) was arbitrary. This prior has been use for some years in the rock lobster assessments.

Recruitment deviations were assumed to be normally distributed with mean zero and bounds that limit recruitment multipliers to the range 0.10 to 10.0. The normal prior on recruitment deviations implies a lognormal distribution of recruitment.

Priors for the points at which selectivity is maximum for males and females were given means equal to the MLS.

3.5 Other values

Structural and fixed values used in this assessment are shown in Table 6.

3.6 Development of a base case

Notation used here is explained in Appendix A.

We started with relative weights, ϖ , of 1 for each dataset and looked at the standard deviations of normalised residuals (sdnr) for each dataset. We tried to adjust these relative weights for all data sets until we obtained sdnrs close to 1. However, the fit to CPUE deteriorated, especially for the recent years, and the minimisation was unstable, reflected in non-positive definite Hessian matrices. A variety of experimental approaches failed to improve this. We abandoned the attempt to produce sdnrs close to 1 and adjusted the weights until we obtained an acceptable fit. At that point we fixed $\ln(\tilde{\sigma})$

at the estimated value and fine-tuned the model by changing phasing, bounds, priors and initial values, but not changing data weights.

The weights used are shown in Table 6 and sdnrs obtained are shown in Table 7. Other weights were used in an exploration of the sensitivity of this procedure. Increasing the weight on PRI had little effect on the fit, so we left the weight for this data set at a low value.

Some parameters were fixed in the base case (see Table 5 and Table 6) as follows.

We fixed χ, the exponent of the relation between CPUE and vulnerable biomass, to 1 in the base case and tested this assumption in a sensitivity trial. The $\ln(\tilde{\sigma})$ was fixed at the estimated value to stabilise the estimation.

The minimum observation error ($\varphi^{j,\min}$) and standard deviation of growth observation error ($\varphi^{j,obs}$) were fixed near the values obtained when the model was fit to tagging data only. Preliminary trials and previous assessments showed these parameters to be badly confounded with other growth parameters, leading to instability.

Both maturity parameters (m_{50} and m_{95-50}) were fixed at values obtained when fitting to the proportion-at-length data only to stabilise the minimisation. Lobsters in CRA 3 are largely mature at sizes represented in the data, so there is little signal from which to estimate maturity.

Parameters describing the maximum point and the right-hand limb of the selectivity curves were fixed at the minimum legal size and the value that gives a nearly asymptotic right-hand limb, respectively. The consequences of fixing the right-hand limb were explored in a sensitivity trial.

4. ASSESSMENT RESULTS

4.1 Base case MPD estimates

4.1.1 Fits to data

Results of the base case MPD estimation are shown in the first column of Table 7. The fit to standardised CPUE is shown in Figure 8 and the residuals in Figure 9. The model fit reasonably well to the pattern of CPUE (see Figure 8), but tended to overestimate SS CPUE before 1990. The model predicted a small spike in CPUE in 1981–82 that does not appear in the data, and underestimated the peak in the late 1990s in both seasons.

Fits to the historical catch rate data were not tight (see Figure 10 and see Figure 11), and again the model tended to overestimate SS and underestimate AW catch rates before 1968, and vice-versa after 1968, leading to seasonal patterns in the residuals. Fitting to pre-recruit indices was very poor in SS but acceptable in most of the AW periods (see Figure 12 and Figure 13). Although the data show an increase in recent years in both seasons, the model estimated decreases in PRI.

Fits to proportions-at-length (see Figure 14) were variable. The observed proportions showed much variability from year to year, especially in samples with low weights, so some variability in the fit stems from this. Low weights reflect the small sample sizes and poor representativeness of some records. For records with high weights, the fits to males and mature females were reasonably good. There were few immature females in the data and their pattern varied from year to year, so fits to this component were especially poor, but these have little weight in the fitting.

Residuals from the fits to proportion-at-length are shown plotted in different ways in Figure 15 through Figure 18. There were a few very large residuals for males and mature females, but most residuals were less than 2. When residuals are plotted against predicted proportions (see Figure 15), there was some tendency for residuals to increase with increasing predicted proportions because of the assumed pattern of standard deviations. A box plot of residuals plotted against lobster size (see Figure 16) shows that high residuals occurred mainly around the MLS for both males and females. A box plot of residuals plotted against lobster size by season (see Figure 17) shows largest residuals just below the MLS for both sexes. In quantile-quantile (q-q) plots of residuals by sex (see Figure 18), residuals between -0.05 and 0.05 have been omitted: these came from the many comparisons in which the observed and predicted proportions were both very small. Residuals for males and mature generally followed the theoretical pattern, but had more large residuals than predicted. For immature females, the q-q plots reflect the poor data quality that results from the very small numbers of immature females observed.

Fits to the tag-recapture data were generally good (see Figure 19), but with some large normalised residuals from sub-legal females. Figure 20 through Figure 24 show the residuals from fits to the tag-recapture plotted in different ways. Figure 20 shows residuals by statistical area, including the CRA 5 areas because the data were from both CRA 3 and CRA 5. Areas 911 and 933 tended to have higher than predicted growth and area 909 had smaller than predicted growth.

Residuals plotted by the number of re-releases (see Figure 21) show little pattern for females. For males, growth for lobsters re-released many times tended to be over-estimated. Residuals plotted by the number of periods between release and recapture and by season of release (see Figure 22) show that for summer releases the model tended to over-estimate growth of lobsters that remained at liberty for long periods.

Growth of the few large lobsters in the data tended to be over-estimated (see Figure 23). Tag type (see Figure 24) showed little effect.

4.1.2 MPD Trajectories

Total biomass is compared with recruited biomass in Figure 25 for each sex. Total biomass is the start-of-season biomass of lobsters of all sizes, without regard for selectivity or vulnerability. Recruited biomass includes only lobsters above the MLS, without regard for selectivity or vulnerability. The total biomass is much larger than the recruited biomass. Immature females have a relatively small contribution to biomass because they mature at a small size. Males, with a higher growth rate and larger size, contribute the most to both biomass components. Recruited biomass showed a nadir in the early 1970s while total biomass showed a fluctuating pattern.

Vulnerable biomass (see Figure 26) takes into account selectivity, vulnerability, MLS and the restrictions on berried females. For consistency this uses current MLS for all years. It shows a pattern similar to that of recruited biomass, but with a nadir near 1970 and much higher biomass afterwards. Exploitation rate (see Figure 27) peaked near 95% in the mid 1980s to early 1990s, declined in the 1990s and switched to lower levels in the SS season in the mid 1990s.

Recruitment estimates (see Figure 28) showed small spikes in 1964 and 1970, and numerous spikes and lows between 1978 and the present. Pre-1975 recruitment was lower than post-1975, and the estimates show a declining trend from 1978.

Initial length structure estimated for the base case fit (see Figure 29) showed most females maturing by 50 mm with a small plus-group for males. The predicted growth increment (see Figure 30) shows a positive predicted increment at the largest model size for males, while the female increment reached zero at 90 mm. Variability of growth was very high for both sexes.

Estimated selectivity-at-size (see Figure 31 and Figure 32) shows the same selectivity in both epochs for males, but a shift to larger sizes for females in the second epoch after escape gaps requirements were changed in 1993.

The trajectory of surplus production plotted against recruited biomass at the start of each year (see Figure 33) indicates a wide range of production values from the lower end of the recruited biomass range.

4.1.3 MPD sensitivity trials with the CRA 3 base case

These sensitivity trials were conducted before the final assessment indicators had been defined. The biomass indicators used to compare sensitivity trials were start-of-season recruited and vulnerable biomass for AW in 1979–88, 1992 and 2003.

Sensitivity of the base case MPD estimates was explored by removing data sets one at a time (see Table 8) to determine whether any one of the data sets appeared to have an especially strong influence on the results. Removing each data set caused some change, but change was most dramatic when proportions-at-length or tag-recapture data were removed. Removal of proportions-at-length caused M to decrease to 0.172, biomass estimates to increase and estimated exploitation rate to decrease. When tag-recapture data were removed, M decreased to 0.261, growth parameter estimates changed markedly, biomass estimates tended to decrease and current exploitation rate increased. Thus these two data sets tend to have opposing effects on biomass estimates.

Removing the CPUE data caused small changes to parameter estimates but substantial changes to biomass estimates (see Table 7). Estimated M was reduced to 0.20 and current exploitation rate increased to 85%. Removing other data sets had comparatively small effects. These trials with data sets removed are not credible as assessment results because much information is discarded, but they are useful to show that the several data sets are not mutually consistent given the model's assumptions and dynamics.

Decreasing the assumed maximum exploitation from 0.95 to 0.80 or 0.90 increased M to near its upper bound (see Table 7), and tended to increase biomass estimates and decrease exploitation rates. Fixing r_{AW}^{male} to 1 and estimating r_{SS}^{male} (the converse of the base case) led to r_{SS}^{male} on its upper bound of 1, (suggesting that the base case assumption was preferable, also a decreased current exploitation rate and somewhat increased biomass.

Doubling non-commercial catches had only small effects on parameter estimates (see Table 7). When a power parameter in the biomass-abundance relation was estimated, the parameter value was 1.158, *indicating a slight hyper-depletion in CPUE. For this run, the fit was improved slightly but parameters* and indicators, except for r_{AW}^{female}, changed little.

These trials suggest that the major sensitivity of the MPDs is to the relative weighting of the various data sets. How MPD sensitivity relates to McMC sensitivity is unknown; it was not possible to conduct all these trials as McMC trials.

4.2 *McMC simulations and Bayesian results*

4.2.1 Fits to data

From the base case we made one long (15 million simulations) McMC chain starting at the MPD parameter estimates. Parameter traces (see Figure 34) showed no signs of pathology. In previous assessments (e.g., Kim et al. 2004), we presented tables of formal diagnostics for each parameter. Some tests commonly fail many parameters, although parameters of interest such as biomass estimates appear uninfluenced. The utility of such tables is not obvious. For this assessment, we focused on the moving and running means of parameter estimates through the chains as the primary diagnostic for reasonable MCMC behaviour (see Figure 35). These suggest no evidence of problematic behaviour or non-convergence in the chains.

Posteriors distributions for the objective function value, estimated and some derived parameters are shown in Figure 36. For most estimated parameters, the MPD estimates were near the centre of the posterior distribution; for biomass estimates the MPD estimates tended to be at the low end of the posterior distribution.

Summaries of the posterior distributions of fits to CPUE and posteriors of the residuals of the fits are shown in Figure 37 and Figure 38 respectively. The fit was generally good, but the discrepancies noted in the MPD persist in the McMC results: for some years the predicted CPUE never matched the observed, causing a consistent pattern in the residuals. The peak AW CPUE of 1997 was under-estimated, but most other AW points were fit well. SS CPUE for 1996–2001 was under-estimated, but the summer fishery was much smaller than the winter fishery in these years (see Figure 2).

Posteriors of the fits to historical catch rate and their residuals (see Figure 39 and Figure 40) showed the same pattern as the MPD fits discussed above (see Figure 10). Fit to the pre-recruit index data (see Figure 41 and Figure 42) was poor: after exploratory work, this data set was given low weight.

The posterior fit to the 2002 AW catch sampling proportion-at-length data (see Figure 43) and posteriors of residuals (see Figure 44) suggest that the relative weight given to proportion-at-length data was high.

4.2.2 Posterior trajectories

Posterior trajectories are shown in Figure 45, Figure 46 and Figure 47 for total, recruited and vulnerable biomass respectively. Index biomass (mid-season vulnerable biomass used as the basis for predicted indices and for biomass indicators) is shown in Figure 48. Trajectories for SL and NSL exploitation rates (see Figure 49 and Figure 50) differed from each other (NSL are much lower) and between seasons (higher in AW in recent years).

Because exploitation rate was constrained by the upper bound in SS in 1984–86 and 1991 in nearly all runs (see Figure 50), uncertainty in vulnerable biomass became very small for these years (see Figure 47). Projected biomass diverged strongly with increasing time. Projected exploitation rates under the 2003 catch levels sometimes exceeded the assumed maximum of 95% in the AW season, suggesting that projected catches might not always be caught.

The posterior trajectory of recruitment deviations (see Figure 51) showed that, although most deviations were close to average, some were consistently high or low in the McMC chain, suggesting that the data (probably the proportions-at-length) contained strong recruitment signals for the model. The pattern also suggests declining recruitment over the past 25 years.

The posterior trajectory of surplus production (see Figure 52) shows very small uncertainty since the mid 1970s. This trajectory is also constrained by the high exploitation rates during mid 1980s, so the low uncertainty should be treated cautiously.

4.3 Summary of the CRA 3 assessment

Posterior distributions of estimated and derived parameters were summarised by their mean, median and 5th and 95th percentiles (see Table 8, left columns). Most parameters were reasonably tightly estimated: exceptions were ln(*R0*) and *M*.

Estimated current index biomass *Bcurr* had a median of 199 t with 5th to 95th percentiles of 154 to 257 t. This is less than the reference biomass *Bref*, which has a median of 329 t (312-348 t). The ratio of *Bcurr* to *Bref* had a median of 60.3% (47.3–77.1%). The minimum biomass estimate *Bmin* was well determined (median 98 t, range 90–106 t). *Bcurr* was well above this, with a median of 203% (157–263%).

By contrast with these estimates, projections were very uncertain. Biomass increased in 59% of runs. Projected biomass *Bproj* had a median of 237 t but its 5–95% range was 70–620 t. The ratio of *Bproj* to *Bcurr* suggests a median expectation of increase with a median of 118%, but this ranged from 40 to 281%. Projected biomass was a median of 243% of *Bmin*, but the range was 72–637%.

4.4 MCMC sensitivities

Summaries of posteriors from the McMC trials are compared with the base case in Table 8. These trials were based on 1 million simulations except for the fixed growth trial with 10 million simulations.

The two fixed growth trials produced less optimistic results than the base case (see Table 8), with much lower *M* estimates. In the second trial, the left hand limb selectivity parameter in epoch 1 for female, η_1^{female} almost tripled and there was a large increase in $v_1^{female,l}$. In both trials, estimates of current and project biomass were lower and exploitation rates higher, ratios of *Bcurr* to *Bref* and *Bmin* were somewhat lower, and ratios of ratios of *Bproj* to *Bcurr*, *Bref* and *Bmin* were substantially lower. The indicator *%increase* decreased to 55% and 49% in these two trials.

When the upper bound and prior for *M* was relaxed ("free *M*"), *M* increased to a median of 0.411 (0.376–0.447) (see Table 8) and projected vulnerable biomass increased to 342 t (109–750 t). Biomass estimates (except for *Bmin*, which was little changed) and the biomass ratios used as indicators were all more optimistic than in the base case. The *%increase* indicator increased to 72%.

In the trial with a declining right-hand limb for the selectivity curve ("domed") (see Table 8), *M* decreased slightly, all biomass estimates increased substantially and the biomass ratios used as indicators were all much more optimistic than in the base case (except for *Bcurr* vs *Bmin*). The *%increase* indicator increased to 86%.

Figure 53 compares the posteriors of *Bcurr* and the 1945 biomass, in this figure called *B0*. The posteriors for *Bcurr* overlapped, although showing the differences discussed above, with the fixed growth trials having smaller values than the base case, and the other two trials showing distributions shifted to the right with respect to the base case. These same differences were shown by *B0*, but were much exaggerated: distributions from the two fixed growth trials overlapped the base case by only a small amount, and the other trials had no overlap with the base case. This comparison suggests that estimates of *B0* are far more sensitive to routine modelling choices than are estimates of *Bcurr*.

When ratios are compared (see Figure 53), those involving *B0* also reflect the pattern just described. Distributions of *Bcurr/Bref* from the five trials overlapped, whereas those of *Bcurr/B0* were almost disjunct. These comparisons suggest that the approach of using a reference biomass is much more stable (less affected by routine modelling choices) than an approach based on *B0* would be.

Figure 54 and Figure 55 respectively compare priors with the posterior distributions for *M* and recruitment deviations obtained from the "implicit prior" McMC trial. All posteriors were identical with the priors. The posterior trajectory of the index biomass, SL and NSL exploitation rates, and recruitment deviations are shown in Figure 56 to Figure 59. Biomass shows a decrease, but estimates were higher than the base case by an order of magnitude, and exploitation rates were commensurately lower. There was no pattern in recruitment. These results show that the priors used and the assumptions implicitly contained in the model structure have little influence on the pattern of results obtained in the base case.

4.5 MCMC retrospectives

A summary of the posterior distributions from the retrospective 2001 McMC is shown in Table 9. The vulnerable biomass trajectories are compared with the base case in Figure 60, the legal exploitation rate trajectories are compared with the base case in Figure 61 and the recruitment deviation trajectories are compared with the base case in Figure 62.

Although the parameter estimates differ little between the retrospective and the base case, and the shapes of trajectories are nearly identical from the 1970s through the late 1990s, trajectories diverge dramatically after 1996, with more optimistic projections from the 2001 retrospective. Projections after 2003 are not directly comparable because the catches used are not the same.

This trial shows some sensitivity of the model to recent data. Without the last two years' data, of which the CPUE data are likely the most critical, the model would produce a much more optimistic assessment.

4.6 Additional projections

After the assessment had been reported to the Plenary, additional projections were made at the request of the NRLMG. These used commercial catch levels of 210 t (as in the base case), 190 and 170 t; and in parallel they used illegal catch levels of 89 t (the base case value) and half this, 45 t. The combination of 210 t commercial and 89 t illegal catch is, of course, the base case described above.

Each catch level was translated into the SL and NSL catches (see Table 10). The seasonal pattern of these assumed catch combinations followed the assumptions used in the base case projections: commercial catch was divided seasonally in the same way as in 2003 and illegal catch followed the seasonal split for commercial catch. As in base case projections, revised catches first apply to the 2005–06 season and the 2004–04 catches are applied in 2004–05.

These projections are made under the assumption that aggregate catches are effectively reduced to the levels shown. The assumption is very important, because projections are sensitive to catch. The model projections that assume the illegal catch is halved (from 89 t to 45 t per year) assume sufficient active intervention by MFish Compliance and the adoption of other management measures to ensure that illegal catch is reduced by 50%. Without those, these projections are meaningless.

The posteriors of biomass indicators (see Table 11) all shifted to the right (higher values) when commercial catch was decreased, and to still higher numbers when illegal catch was halved. When catches were decreased, more runs increased and fewer runs fell below *Bmin* (see Table 11; see Figure 63 and Figure 64). The high uncertainty in projections noted in the assessment remained (see Figure 65 and Figure 66).

5. DISCUSSION

5.1 Model and data

Changes to the model for the 2004 assessment were relatively minor except for code incorporating the effect of the Te Tapuwae o Rongokako Marine Reserve. The Working Group chose not to explore the effect of this change on the results in sensitivity trials. The specific way in which the effect of the reserve was modelled was not the only option, but was considered most likely to address reality appropriately. For instance, a study in Victoria (Hobday et al. 2005) concluded that, even with an assumed 10% emigration from MPAs, the main effect of a reserve was to slow down rebuilding of the fishery because effort was displaced into unprotected areas. This study supports the suggestion of

Shipp (2003) that reserves are not as effective at delivering sustainability objectives as other management methods for marine species.

Compiling the data file was relatively straightforward. Two items worth noticing were first, that assumed recreational and customary catches were flat from 1945 to the present. In the past we assumed that recent recreational catches were higher than historical catches and we constructed a ramped catch vector. The temporal pattern of such catches has a larger effect than the actual level of such catches. The effect of the change in 2003 was not explored, and without having historical data the Working Group has probably made a reasonable decision.

Second, we used a combination of tag-recapture data from CRA 3 and CRA 5 after first comparing growth estimates from the same overlapping range of sizes. This was a response to the lack of data from larger lobster sizes in CRA 3. Again, the effects of this specific decision were not explored, although we know that growth estimates from the CRA 3 data tagging alone are somewhat different from those from the combined data (see Table 8). As in most areas, there is a need for more tag-recapture data from larger animals.

5.2 Model behaviour

The model behaved better than the model in the 2001 CRA 3 assessment (Breen et al. 2002). We were able to fit to recent CPUE data, and we had less trouble finding a credible and useable base case than in 2001. Behaviour was by no means exemplary, and we fixed a variety of parameters for a variety of reasons, most notably $\ln(\tilde{\sigma})$ to solve apparent local minimum problems. The McMC behaviour appears to have been good.

The model fit reasonably well to the data set in the base case, except for the pre-recruit index. It is possible that escape gaps allow such a high proportion of small lobsters to escape that any abundance signal is lost. Growth parameter estimates were not markedly different from the values estimated from tagging data alone.

The fits obtained varied when CPUE, proportions-at-length or tag-recapture data were excluded. It is unreasonable to exclude data in practice, but these sensitivity trials suggest some inconsistencies among the data sets. This is often the case, especially between the two main data sets with growth information. Other sensitivity trials were more benign.

The McMC sensitivity trials also demonstrated that results are uncertain to modelling choices, especially data weighting and the prior on *M*. More optimistic results were obtained when we relaxed the prior on *M*. Recent assessment usage, based on a review of the literature for temperate lobsters, has been to use a mean for the prior on *M* of 0.10, although tropical lobsters may have values much higher. Thus a value of 0.30 (or 0.40 in the "free *M*" trial) seems "too high". The combination of model and data, on the other hand, are clearly compatible with such estimates for CRA 3. It is possible that the model uses *M* as an alias for other processes such as reduced vulnerability of larger lobsters from whatever cause. This would be supported by the "domed selectivity" trail: when the right-hand limb of selectivity-at-size was estimated, it declined steeply and this led to much more optimistic results than in the base case. By contrast, fixing growth to values obtained from the tag-recapture data alone led to much more pessimistic results than in the base case, with much lower values of *M*.

The McMC trials are not all realistic as alternative assessments. The fixed growth trials essentially ignore all the growth information content of the proportion-at-length data, which is not credible. The "domed" selectivity trial allows the model to have large numbers of large cryptic lobsters in the population, which is a dangerous approach to use without having independent supporting evidence. The trials show the uncertainty associated with *M* and growth parameters, and the fixed growth trials suggest that relative weightings of the catch sampling and tagging data sets are important to the specific results of the base case, and hence that the assessment is far more uncertain than the base case McMC results would indicate.

Similarly the retrospective trial showed a sensitivity of the model to recent data, in turn suggesting that new data could change the estimates of current and reference biomass, adding to the overall uncertainty of the assessment.

5.3 CRA 3 assessment

The assessment, based on the base case McMC results, suggests a stock that is very likely to be above the limit reference point *Bmin* (see Table 8) but is probably below the target, *Bref*. Current exploitation rate is estimated to be 45–60% for the AW fishery on the SL biomass. In general the picture is of a fishery not in trouble (above *Bmin*), but with some concern because of declining CPUE. Current biomass is lower than target biomass (*Bcurr* is 50–75% of *Bref*) and exploitation rates are higher than desirable (50%).

Projections are very uncertain because recruitment is so variable. At the 2003 catch levels, the median expectation would be for a slight increase in biomass over 3 years, probably not reaching *Bref* in that time. However, the range of *Bproj/Bcurr* is from 40% to 281%. The risk of biomass falling below *Bmin* is about 14%.

Results, especially those of the alternative projections, have been considered by the NRLMG in forming its annual advice to the Minister.

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7. REFERENCES

Annala, J.H. (1983). New Zealand rock lobsters: biology and fishery. *Fisheries Research Division Occasional Publication 42.* 36 p.

Annala, J.H.; Esterman, D.B. (1986). Yield estimates for the New Zealand rock lobster fishery. pp. 347–358 *In* G.S. Jamieson; N.F. Bourne (eds.) North Pacific Workshop on Stock Assessment and Management of Invertebrates. *Canadian Special Publication of Fisheries and Aquatic Sciences 92.*

Annala, J.H.; M.R. King. (1983). The 1963–73 New Zealand rock lobster landings by statistical area. *Fisheries Research Division Occasional Publication: Data Series 11.* 20 p.

Bentley, N.; Breen, P.A.; Kendrick, T.H. (2001). Assessment of the CRA 3 and NSS substocks of red rock lobster (*Jasus edwardsii*) for 2000. *New Zealand Fisheries Assessment Report 2001/69:* 84 p.

Bergh, M.O.; Johnston, S.J. (1992). A size-structured model for renewable resource management, with application to resources of rock lobster in the south-east Atlantic. *South African Journal of Marine Science 12*: 1005-1016.

Booth, J.D.; Breen, P.A. (1994). The New Zealand fishery for *Jasus edwardsii* and *J. verreauxi*. pp. 64–75, *In* Phillips, B.F.; Cobb, J.S.; Kittaka, J. (eds.) Spiny lobster management. Blackwell Scientific, Oxford.

Booth, J.D.; Robinson, M.; Starr, P.J. (1994). Recent research into New Zealand rock lobsters, and a review of rock lobster catch and effort data. New Zealand Fisheries Assessment Research Document 94/7. 56 p. (Unpublished report held in NIWA Greta Point library, Wellington.)

Breen, P.A. (1991). Assessment of the red rock lobster (*Jasus edwardsii*) North and South Island stock, November 1991. New Zealand Fisheries Assessment Research Document 91/16. 24 p. (Unpublished report held in NIWA Greta Point library, Wellington.)

Breen, P.A., Kim, S.W.; Starr, P.J.; Bentley, N. (2002). Assessment of the red rock lobsters (*Jasus edwardsii*) in area CRA 3 in 2001. *New Zealand Fisheries Assessment Report 2002/27*. 82 p.

Breen, P.A., Booth, J.D.; Tyson, P.J. (1988). Feasibility of a minimum size limit based on tail width for the New Zealand red rock lobster, *Jasus edwardsii*. *New Zealand Fisheries Technical Report 6*. 16 p.

Breen, P.A.; Kendrick, T.H. (1998). The 1996 assessment for the New Zealand red rock lobster (*Jasus edwardsii*) fishery. New Zealand Fisheries Assessment Research Document 98/13. 42 p. (Unpublished report held in NIWA Greta Point library, Wellington.)

Breen, P.A.; Kim, S.W.; Andrew, N.L. (2003). A length-based Bayesian stock assessment model for abalone. *Marine and Freshwater Research 54(5):* 619–634.

Breen, P.A.; McKoy, J.L. (1988). An annotated bibliography of the red rock lobster, *Jasus edwardsii*, in New Zealand. *New Zealand Fisheries Occasional Publication 3*. 43 p.

Francis, R.I.C.C. (1999). Moving towards *Bmsy*. New Zealand Fisheries Assessment Research Document 99/2. 23 p. (Unpublished report held in NIWA Greta Point library, Wellington.)

Hobday D.; A. Punt; D. Smith. (2005). Modelling the effects of marine protected areas on Victoria's southern rock lobster, *Jasus edwardsii*, fishery. *Marine and Freshwater Research 39*: 679–686.

Kim, S.W.; Bentley, N.; Starr, P.J.; Breen, P.A. (2004). Assessment of red rock lobsters (*Jasus edwardsii*) in CRA 4 and CRA 5 in 2003. *New Zealand Fisheries Assessment Report 2004/8*. 165 p.

Maunder, M. N.; Starr, P. J. (1995). Rock lobster standardised CPUE analysis. New Zealand Fisheries Assessment Research Document 95/11. 28 p. (Unpublished report held in NIWA Greta Point library, Wellington.)

McAllister, M.K.; Pikitch, E.K.; Punt, A.E; Hilborn, R. (1994). A Bayesian approach to stock assessment and harvest decisions using the sampling/resampling importance algorithm. *Canadian Journal of Fisheries and Aquatic Sciences 51:* 2673–2687.

Meyer, R.; Millar, R.B. (1999). Bayesian stock assessment using a state-space implementation of the delay-difference model. *Canadian Journal of Fisheries and Aquatic Sciences 56*: 37–52.

National Research Council. (1998). Improving fish stock assessments. National Academy Press, Washington. ix + 243 p.

Punt, A.; Hilborn, R. (1997). Fisheries stock assessment and decision analysis: The Bayesian Approach. *Reviews in Fish Biology and Fisheries 7:* 35–63.

Punt, A.E; Kennedy, R.B. (1997). Population modelling of Tasmanian rock lobster resources. *Marine and Freshwater Research 48*: 967–980.

Shipp, R.L. (2003). A perspective on marine reserves as a fishery management tool. *Fisheries 28(12):* 10–26.

Sorenson, J.H. (1970). New Zealand rock lobster *Jasus edwardsii* carapace and tail measurements. *New Zealand Marine Department Fisheries Technical Report 53.* 32 p.

Starr, P.J., Bentley, N.; Breen, P.A.; Kim, S.W. (2003). Assessment of red rock lobsters (*Jasus edwardsii*) in CRA 1 and CRA 2 in 2002. *New Zealand Fisheries Assessment Report 2003/41.* 119 p.

Street, R.J. (1973). Trend in the rock lobster fishery in southern New Zealand, 1970–1971. *New Zealand Marine Department Fisheries Technical Report No. 116.* 32 p.

Sullivan, K.J. (2004). Report from the Mid-Year Fishery Assessment Plenary: Stock assessments and yield estimates. MFish, Wellington. 46 p. (Unpublished report held in NIWA Greta Point library, Wellington.)

Sullivan, P.J.; Lai, H.-L.; Gallucci, V.F. (1990). A catch-at-length analysis that incorporates a stochastic model of growth. *Canadian Journal of Fisheries and Aquatic Sciences 47:* 184–198.

Zheng, J.; Murphy, M.C.; Kruse, G.H. (1995). A length-based population model and stock-recruitment relationships for red king crab, *Paralithodes camtschaticus*, in Bristol bay, Alaska. *Canadian Journal of Fisheries and Aquatic Sciences 52:* 1229–1246.

Table 1: Data types and sources for the 2004 assessment of CRA 3. Year codes apply to the first 9 months of each fishing year, *viz 1998-99 is called 1998. NZRLIC – New Zealand Rock Lobster Industry* Council; FSU – Fisheries Statistics Unit; CELR – Catch and Effort Landing Returns.

Data type	Data source	Begin year	End year
Historical catch rate	Annala & King (1983)	1963	1972
CPUE	FSU & CELR	1979	2003
Historical proportions-at-size	MFish database	1961	1983
Research proportions-at-size	MFish	1986	2003
Logbook proportions-at-size	NZRLIC	1993	1998
Historical tag recovery data	MFish database	1975	1983
Current tag recovery data	NZRLIC & MFish	1995	2003
Historical MLS regulations	Annala (1983)	1945	2000
Escape gap regulation changes	Annala (1983)	1945	2000

Table 2: Estimates of illegal catch (t) for the 2004 assessment of CRA 3. For the years not listed, the assessment used values interpolated linearly.

Fishing year	Catch
1979	27.7
1987	135.0
1990	288.0
1992	250.0
1994	42.0
1995	63.0
1996	84.0
1997	64.0
1998	90.5
1999	136.0
2000	78.0
2001	75.0
2002	75.0
2003	89.5

Table 3: Summary of historical minimum size limit regulations for CRA 3. Regulation changes through 1959 are taken from Annala (1983); changes from 1988 to 1990 are summarised from Table 1 in Booth et al. (1994). Regulations are expressed in inches (designated as ") or mm. Equivalent measurements in mm tail width were made using the conversion factors of Sorenson (1970) and Breen et al. (1988). The lower size limit of 5.75 inches tail length was used from 1952 to 1958. Abbreviations: TL, total length; tl, tail length; TW, tail width, AW, autumn-winter season; SS, spring-summer season.

	Regulation		Model interpretation in tail width (mm)	
Year	Males	Females	Males	Females
1945	No limit	No limit	No limit	No limit
1950	9" TL	9" TL	47	49
1952	10" TL or 5.75" tl	10" TL or 5.75" tl	51	53
1959	6" tl	6" tl	53	56
1988	54 mm TW	58 mm TW	54	58
1992	54 mm TW	60 mm TW	54	60
1993 AW	52 mm TW	prohibited	52	100
1993 SS	54 mm TW	60 mm TW	54	60

Table 4: Summary of the number and sources of tag recoveries from CRA 3 used in the 2004 assessment. NZRLIC indicates data from the New Zealand Rock Lobster Industry Council (on the MFish database).

	CRA3		CRA5	
	Male	Female	Male	Female
Older data	1271	530	384	139
RLIC	329	54	997	498
Total	1600	584	1381	637

Table 5: Parameters estimated in the model, their upper and lower bounds, base case prior distributions and initial values. Parameters were estimated in several phases as shown; in phase 2, for instance, all parameters of phase 2 or less are estimated and the others remain at their initial values. Negative phases indicate fixed values (see also Table 6). Prior types: U, uniform; N, normal; L, lognormal. For definitions of parameters see Appendix A. Initial values in bold indicate a parameter that was held fixed in the base case. –, not applicable.

Parameter	Function	Phase	LB	UB	Type	Mean	c.v.	Initial value
$\ln(R_0)$	Natural log of base recruitment	3	1	25	U	–	–	15
ε_y	Recruitment deviation parameters	3	-2.3	2.3	N	0	0.4	0
M	Natural mortality	5	0.01	0.35	L	0.12	0.1	0.25
$\ln(q^I)$	Log of catchability for CPUE	1	-25	0	U	–	–	-6.9
$\ln(q^{CR})$	Log of catchability for CR	1	-25	2	U	–	–	-16
$\ln(q^{PRI})$	Log of catchability for PRI	1	-25	0	U	–	–	-14
d_{50}^{male}	Growth at 50 mm	2	1	20	U	–	–	1.738
d_{50}^{female}	Growth at 50 mm	2	1	20	U	–	–	2.259
d_{50-80}^{male}	Growth diff. between 50 and 80 mm	2	0.001	30	U	–	–	0.0698
d_{50-80}^{female}	Growth diff. between 50 and 80 mm	2	0.001	30	U	–	–	1.1408
CV^{male}	c.v. of expected growth increment	2	0.01	5	U	–	–	0.9062
CV^{female}	c.v. of expected growth increment	2	0.01	5	U	–	–	1.1408
h^{male}	Shape parameter for growth	4	0.1	10	U	–	–	7.6
h^{female}	Shape parameter for growth	4	0.1	10	U	–	–	5
r_{AW}^{male}	Relative seasonal vulnerability	3	0.01	1	U	–	–	0.8
r_{AW}^{female}	Relative seasonal vulnerability	3	0.01	1	U	–	–	0.8
r_{SS}^{female} and r_{SS}^{femmat}	Relative seasonal vulnerability	3	0.01	1	U	–	–	0.8
r_{AW}^{femmat}	Relative seasonal vulnerability	3	0.01	1	U	–	–	0.8
η_1^{male}	Size at maximum selectivity	-3	30	80	N	52	12	**52**
η_1^{female}	Size at maximum selectivity	-3	30	80	N	60	12	**56**
η_2^{male}	Size at maximum selectivity	-3	30	80	N	52	12	**52**
η_2^{female}	Size at maximum selectivity	-3	30	80	N	60	12	**60**
$v_1^{male,l}$	Shape of left-hand limb selectivity	3	0.001	50	U	–	–	3.77
$v_1^{female,l}$	Shape of left	3	0.001	50	U	–	–	7.55
$v_2^{male,l}$	Shape of left	3	0.001	50	U	–	–	3.77
$v_2^{female,l}$	Shape of left	3	0.001	50	U	–	–	7.55

Table 6: Structural and fixed values used in the base case assessment. For definitions of parameters see Appendix A.

Variable	Function	Value
$\tilde{S}_1$	Lower edge of smallest size bin	30
$\bar{S}_{s_{\max}}$	Centre of largest size bin	91
$s_{\max}$	Number of size bins	31
a^{male}	Scalar of length-weight relation	4.16E-06
a^{female}	Scalar of length-weight relation	1.30E-05
b^{male}	Exponent of length-weight relation	2.935
b^{female}	Exponent of length-weight relation	2.545
ϕ	Mean size of recruits	32
γ	Standard deviation of size of recruits	2
$U^{\max}$	Maximum exploitation rate per period	0.9
f_k^g	Moult probability for sex *g* in season *k*	Males: AW 1 SS 1 Females: AW 0, SS 1
χ	Shape parameter for biomass - CPUE relation	Fixed at 1.0
$\ln(\tilde{\sigma})$	*Log of common sigma*	-0.809
$\varphi^{j,\min}$	Minimum std. dev. of growth increment	1
$\varphi^{j,obs}$	Standard deviation of growth observation error	0.5
m_{50}	Size at which 50% of females mature	45.7
m_{95-50}	Difference between sizes at which 50% and 95% of females mature	5.86
w^g	Shape parameter for the right hand limb of the selectivity curve for sex *g*	50 except in sensitivity trial
λ	Parameter for mixing left and right halves of selectivity curves	5
ϖ^I	Relative weight applied to CPUE likelihoods	1
ϖ^{CR}	Relative weight applied to CR likelihoods	0.5
ϖ^{PRI}	Relative weight applied to PRI likelihoods	0.45
ϖ^{p}	Relative weight applied to proportions-at-size	7
ϖ^{TAG}	Relative weight applied to tagging data	0.4
	Handling mortality rate multiplier on SL fishery exploitation rate	0.1
	CPUE process error	0.25
	Sigma for catch rate (CR)	0.3
	Sigma for pre-recruit index (PRI)	0.3
	Assumed maximum seasonal vulnerability	AW males
	Switch from Epoch 1 to Epoch 2 (selectivity change)	SS 1993
	Projected size-limited catch (t)	215
	Projected not size-limited catch (t)	120

Table 7: MPD parameter estimates, negative log likelihoods and performance indicators from the CRA 3 base case and sensitivity trials described in the text. LF refers to proportions-at-size data. Dark shading in the parameters indicates fixed values; in the likelihoods and sdnrs it indicates that data were not fitted; *light shading shows values that* changed substantially from the base case.

Index	1	2	3	4	5	6	7	8	9	10	11
Quantity	Base case	NoCPUE	NoCR	NoPRI	NoLFs	NoTag	MaxU 0.8	MaxU 0.9	Vulnswitch2	DoubleD non-comm. catch	Est. χ
f(total)	-101.8	-230.6	-233.1	-117.6	9569.4	-9623.4	-67.9	-92.9	-88.0	-113.3	-108.4
f(CPUE)	29.7	711302.0	32.7	28.1	-28.4	28.0	33.6	30.3	50.4	32.0	26.6
f(CR)	95.8	98.2	78122.3	96.0	87.3	93.9	93.4	94.8	94.1	94.3	96.0
f(PRI)	3.8	4.5	3.8	13804.9	0.9	5.7	3.5	3.7	1.6	3.8	2.6
f(LFs)	-9792.6	-9858.8	-9796.6	-9793.6	-1588.1	-9828.6	-9774.4	-9787.5	-9790.7	-9795.8	-9791.0
f(tags)	9483.4	9479.6	9482.8	9483.4	9480.6	12032.8	9486.1	9484.1	9483.3	9482.8	9483.1
f(Priors)	33.9	-15.7	1.1	23.8	-5.4	19.8	47.3	38.3	27.9	28.9	29.8
f(Rdevs)	44.0	61.5	42.8	44.3	34.5	57.4	41.7	43.0	45.2	40.5	44.5
penalty(U)	0.2	0.0	0.3	0.2	0.0	0.4	0.9	0.4	0.2	0.2	0.1
$\ln(R_0)$	14.5	13.9	14.4	14.5	13.8	14.0	14.8	14.6	14.4	14.5	14.5
M	0.306	0.204	0.274	0.310	0.172	0.261	0.350	0.320	0.287	0.290	0.293
χ	1*	1*	1*	1*	1*	1*	1*	1*	1*	1*	1.158
$\ln(q^I)$	-5.79	-25.00	-5.76	-5.78	-6.11	-5.64	-6.01	-5.85	-5.86	-5.84	-5.95
$\ln(q^{CR})$	-1.87	-1.98	-25.00	-1.86	-3.18	-1.83	-1.89	-1.87	-1.99	-1.99	-1.90
$\ln(q^{PRI})$	-13.71	-13.50	-13.64	-25.00	-13.11	-13.79	-13.86	-13.75	-13.77	-13.76	-13.70
d_{50}^{male}	1.721	1.734	1.718	1.722	1.721	1.336	1.688	1.710	1.718	1.723	1.728
d_{50}^{female}	2.414	2.247	2.397	2.417	2.220	1.000	2.464	2.434	2.432	2.394	2.408
d_{50-80}^{male}	0.086	0.097	0.047	0.083	0.001	1.450	0.056	0.076	0.085	0.079	0.094
d_{50-80}^{female}	0.818	0.734	0.810	0.819	0.850	0.132	0.871	0.839	0.837	0.809	0.819
CV^{male}	0.998	0.987	1.000	0.998	1.016	0.726	1.008	1.001	0.999	0.997	0.997
CV^{female}	1.124	1.138	1.129	1.123	1.101	1.399	1.111	1.118	1.117	1.129	1.127
h^{male}	5.96	6.44	6.14	5.98	8.59	9.21	5.90	5.93	5.98	5.98	5.87
h^{female}	4.18	3.20	4.04	4.20	1.10	10.00	4.16	4.17	4.06	4.05	4.12
r_{AW}^{male}	0.8437	1.0000	0.8333	0.8275	0.7036	0.7738	0.8367	0.8411	1.0000	0.8423	0.8754

Index	1	2	3	4	5	6	7	8	9	10	11
Quantity	Base case	NoCPUE	NoCR	NoPRI	NoLFs	NoTag	MaxU 0.8	MaxU 0.9	Vulnswitch2	DoubleD non-comm. catch	Est. χ
r_{AW}^{female}	0.6547	1.0000	0.7275	0.6752	0.2143	1.0000	0.0100	0.4065	0.7664	0.9021	0.2420
$r_{SS}^{female} = r_{SS}^{femmat}$	0.5759	0.4697	0.5583	0.5794	0.1640	1.0000	0.6754	0.6100	0.5706	0.5859	0.5431
r_{AW}^{femmat}	0.1393	0.1495	0.1287	0.1315	0.1524	0.2430	0.1541	0.1448	0.1561	0.1411	0.1401
η_1^{male}	2.557	2.658	2.581	2.560	0.033	3.883	2.554	2.557	2.570	2.568	2.536
η_1^{female}	3.283	3.406	3.253	3.285	50.000	2.323	3.006	3.186	3.213	3.254	3.290
η_2^{male}	2.676	2.731	2.700	2.680	0.184	4.395	2.638	2.663	2.691	2.688	2.674
η_2^{female}	5.071	5.035	4.959	5.128	14.488	3.771	4.830	4.983	4.990	5.028	5.096
sdnr(CPUE)	1.92	7.04	1.95	1.90	1.16	1.90	1.96	1.92	2.12	1.94	1.89
sdnr(CR)	1.41	1.48	2.22	1.41	1.08	1.34	1.32	1.37	1.35	1.35	1.41
sdnr(PRI)	1.00	1.03	1.00	1.07	0.83	1.09	0.98	0.99	0.87	0.99	0.93
sdnr(LFs)	0.52	0.49	0.52	0.52	1.92	0.50	0.53	0.52	0.52	0.52	0.52
sdnr(tags)	1.13	1.14	1.13	1.13	1.12	1.66	1.13	1.13	1.13	1.13	1.13
$BVULN_{03,AW}$	182	94	173	173	305	140	242	199	211	190	192
$BRECT_{03,AW}$	482	344	503	470	906	292	550	498	497	499	503
$BVULN_{79\text{-}88,AW}$	154	236	150	151	257	125	198	167	180	161	156
$BVULN_{92,AW}$	118	142	116	116	126	117	152	128	139	127	124
$USL_{03,AW}$ (%)	52.7	84.9	55.7	55.9	43.6	58.6	41.3	49.0	45.6	51.4	50.2

Table 8: ***Summary statistics for posterior distributions from McMC simulations*** **for the CRA 3 base case and four sensitivity trials described in the text. Shading indicates fixed parameters.**

			Base case			Fixed growth			Fixed growthA3			free M			Domed
Parameter	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95
$\ln(R_0)$	14.33	14.50	14.67	13.53	13.63	13.74	13.49	13.54	13.59	14.73	14.93	15.15	13.93	14.05	14.18
M	0.283	0.309	0.335	0.163	0.171	0.181	0.148	0.156	0.162	0.376	0.411	0.447	0.256	0.280	0.307
$\ln(q^I)$	-5.86	-5.81	-5.75	-5.79	-5.75	-5.70	-5.83	-5.79	-5.74	-5.93	-5.86	-5.80	-5.85	-5.80	-5.75
$\ln(q^{CR})$	-2.09	-1.90	-1.71	-2.06	-1.92	-1.77	-2.16	-2.04	-1.91	-2.10	-1.90	-1.70	-1.82	-1.64	-1.45
$\ln(q^{PRI})$	-13.85	-13.72	-13.60	-13.59	-13.47	-13.35	-13.65	-13.53	-13.41	-14.00	-13.87	-13.73	-13.80	-13.68	-13.55
d_{50}^{male}	1.67	1.71	1.75	1.74	1.74	1.74	1.70	1.70	1.70	1.70	1.73	1.78	1.79	1.82	1.85
d_{50}^{female}	2.27	2.42	2.56	2.26	2.26	2.26	1.85	1.85	1.85	2.44	2.59	2.75	2.07	2.28	2.48
d_{50-80}^{male}	0.011	0.082	0.198	0.070	0.070	0.070	0.200	0.200	0.200	0.014	0.104	0.234	0.206	0.288	0.378
d_{50-80}^{female}	0.510	0.821	1.115	1.141	1.141	1.141	0.770	0.770	0.770	0.677	0.999	1.294	0.113	0.504	0.949
CV^{male}	0.977	1.009	1.042	0.906	0.906	0.906	0.830	0.830	0.830	0.971	1.001	1.034	0.895	0.921	0.947
CV^{female}	1.056	1.124	1.200	1.141	1.141	1.141	0.990	0.990	0.990	1.020	1.085	1.155	1.094	1.168	1.258
h^{male}	5.36	5.99	6.50	6.74	6.74	6.74	6.48	6.48	6.48	5.29	5.99	6.53	7.52	7.86	8.19
h^{female}	3.48	4.20	5.01	0.10	0.10	0.10	1.56	1.56	1.56	3.72	4.38	5.09	4.43	5.55	6.68
r_{AW}^{male}	0.8012	0.8443	0.8924	0.8256	0.8716	0.9207	0.8199	0.8619	0.9081	0.7766	0.8184	0.8643	0.7970	0.8417	0.8873
r_{AW}^{female}	0.0621	0.4976	0.9467	0.0636	0.5116	0.9488	0.0895	0.5669	0.9546	0.0590	0.4952	0.9451	0.0428	0.3902	0.8990
$r_{SS}^{female} = r_{SS}^{femmat}$	0.4937	0.5778	0.6732	0.4955	0.5612	0.6488	0.5097	0.8416	0.9868	0.5586	0.6464	0.7484	0.4913	0.5814	0.6686
r_{AW}^{femmat}	0.1155	0.1400	0.1671	0.0994	0.1198	0.1472	0.1038	0.1633	0.1973	0.1296	0.1564	0.1854	0.0862	0.1092	0.1376
η_1^{male}	2.39	2.56	2.75	2.44	2.97	3.52	2.57	3.12	3.75	2.34	2.51	2.70	2.58	2.82	3.09
η_1^{female}	2.79	3.28	3.85	0.67	2.58	4.24	7.85	10.11	11.88	2.76	3.23	3.80	2.38	2.90	3.44
η_2^{male}	2.59	2.68	2.77	2.95	3.15	3.35	2.88	3.08	3.29	2.53	2.61	2.71	1.36	1.44	1.53
η_2^{female}	4.58	5.09	5.63	3.57	4.64	5.83	4.64	6.27	8.38	4.67	5.14	5.66	4.06	4.57	5.20
$v_1^{male,1}$	52	52	52	51.5	52.1	52.8	51.7	52.4	53.1	52	52	52	52	52	52

			Base case			Fixed growth			Fixed growthA3			free M			Domed
Parameter	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95
$v_1^{female,l}$	56	56	56	53.8	56.0	57.8	63.6	69.0	72.1	56	56	56	56	56	56
$v_2^{male,l}$	52	52	52	52.1	52.4	52.6	52.0	52.2	52.5	52	52	52	49	49	49
$v_2^{female,l}$	60	60	60	58.5	59.7	61.2	60.6	63.8	67.6	60	60	60	60	60	60
$UNSL_{04\,AW}$ (%)	8.9	10.0	11.1	10.5	11.7	13.0	10.0	11.1	12.3	8.1	9.1	10.3	9.5	11.0	12.7
$USL_{04\,AW}$ (%)	45.7	51.2	57.1	53.2	59.5	66.3	50.5	56.3	62.9	41.4	46.9	52.7	48.1	54.9	62.8
$UNSL_{07\,AW}$ (%)	4.3	8.1	17.5	5.0	10.5	23.6	5.7	11.0	22.1	3.6	6.3	13.3	3.8	6.4	13.6
$USL_{07\,AW}$ (%)	18.8	41.5	98.9	21.2	53.6	99.6	25.2	57.7	99.5	16.3	31.3	81.2	17.1	30.4	78.4
Bmin	90	98	106	85	91	99	84	90	97	88	96	107	112	121	130
Bref	312	329	348	295	310	325	308	323	338	327	348	373	310	326	342
Bcurr	154	199	257	121	163	214	137	179	226	178	234	309	130	209	321
Bproj	70	237	620	52	177	536	55	171	451	109	342	750	108	379	738
Bcurr/Bmin (%)	156.9	203.3	262.9	133.6	178.0	234.7	153.6	198.1	249.5	185.2	243.1	321.0	107.4	173.5	266.0
Bcurr/Bref (%)	47.3	60.3	77.1	39.7	52.6	68.4	43.1	55.4	68.8	52.5	67.2	87.1	40.1	64.2	97.5
Bproj/Bcurr (%)	39.9	118.9	281.2	35.6	110.9	287.1	34.8	97.0	225.5	53.5	143.9	294.3	67.7	178.3	302.8
Bproj/Bmin (%)	72.4	243.5	636.8	57.4	193.6	588.9	61.7	191.2	500.0	113.2	355.1	786.2	88.1	315.8	605.4
Bproj/Bref (%)	21.4	72.0	187.6	16.8	56.7	173.3	17.1	53.5	139.4	31.7	97.1	216.2	33.0	116.9	223.5
%increase		58.8			54.5			48.6			71.6			85.7	

Table 9: Parameter estimates from McMC retrospective analysis compared with the base case.

	Base case			Retro 2001		
Parameter	0.05	Median	0.95	0.05	Median	0.95
$\ln(R_0)$	14.33	14.50	14.67	14.37	14.54	14.74
M	0.283	0.309	0.335	0.282	0.308	0.335
$\ln(q^I)$	-5.86	-5.81	-5.75	-5.98	-5.91	-5.84
$\ln(q^{CR})$	-2.09	-1.90	-1.71	-2.08	-1.90	-1.71
$\ln(q^{PRI})$	-13.85	-13.72	-13.60	-14.13	-13.98	-13.83
d_{50}^{male}	1.67	1.71	1.75	1.67	1.71	1.75
d_{50}^{female}	2.27	2.42	2.56	2.25	2.41	2.57
d_{50-80}^{male}	0.011	0.082	0.198	0.014	0.093	0.219
d_{50-80}^{female}	0.510	0.821	1.115	0.439	0.777	1.103
CV^{male}	0.977	1.009	1.042	0.976	1.008	1.042
CV^{female}	1.056	1.124	1.200	1.051	1.120	1.196
h^{male}	5.36	5.99	6.50	5.29	6.02	6.53
h^{female}	3.48	4.20	5.01	3.67	4.50	5.39
r_{AW}^{male}	0.8012	0.8443	0.8924	0.7962	0.8397	0.8842
r_{AW}^{female}	0.0621	0.4976	0.9467	0.0571	0.4520	0.9382
$r_{SS}^{female} = r_{SS}^{femmat}$	0.4937	0.5778	0.6732	0.3906	0.4675	0.5574
r_{AW}^{femmat}	0.1155	0.1400	0.1671	0.1171	0.1459	0.1781
η_1^{male}	2.39	2.56	2.75	2.37	2.55	2.75
η_1^{female}	2.79	3.28	3.85	2.96	3.52	4.25
η_2^{male}	2.59	2.68	2.77	2.49	2.59	2.69
η_2^{female}	4.58	5.09	5.63	4.99	5.57	6.29
$UNSL_{04\,AW}$ (%)	8.9	10.0	11.1	4.1	4.6	5.2
$USL_{04\,AW}$ (%)	45.7	51.2	57.1	28.4	31.9	35.8
$UNSL_{07\,AW}$ (%)	4.3	8.1	17.5	2.6	4.1	7.3
$USL_{07\,AW}$ (%)	18.8	41.5	98.9	11.0	17.9	34.5
$Bmin$	90	98	106	91	99	111
$Bref$	312	329	348	341	365	391
$B_{01\,AW}$	247	273	337	496	607	733

Table 10: Summary of the catch levels (t) used in additional projections. The catch model assumes a small percentage of "reported illegal" catch that is subtracted from the commercial catch.

Commercial	Illegal	Customary	Recreational	SL	NSL
210	89	20	20	226	110
190	89	20	20	206	110
170	89	20	20	186	110
210	45	20	20	228	65
190	45	20	20	208	65
170	45	20	20	188	65

Table 11: **Summary of indicators from additional three-year projections made under each commercial and illegal (in parentheses) catch level (see Table 10). Shading indicates the base case.**

Catch level	210 (89)			190 (89)			170 (89)		
	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95
$UNSL_{07\,AW}$ (%)	4.3	8.1	17.5	4.1	7.6	16.7	4.0	7.2	15.4
$USL_{07\,AW}$ (%)	18.8	41.5	98.9	16.8	35.2	97.0	14.9	30.1	80.0
Bproj(%)	70	237	620	76	265	652	94	293	683
Bproj/Bcurr(%)	39.9	118.9	281.2	44.2	132.8	295.6	53.8	147.3	309.9
Bproj/Bmin(%)	72.4	243.5	636.8	78.7	271.6	667.8	96.6	299.8	698.5
Bproj/Bref(%)	21.4	72.0	187.6	23.1	80.3	196.9	28.4	88.6	206.1
%Bincrease		59			67			74	
%>Bmin		86			91			95	

Catch level	210 (45)			190 (45)			170 (45)		
	0.05	Median	0.95	0.05	Median	0.95	0.05	Median	0.95
$UNSL_{07\,AW}$ (%)	2.4	4.3	9.2	2.3	4.1	8.5	2.2	3.9	7.8
$USL_{07\,AW}$ (%)	15.9	33.0	89.1	14.1	28.2	72.6	12.5	24.1	57.3
Bproj(%)	85	280	672	106	309	703	130	338	734
Bproj/Bcurr(%)	49.8	140.9	304.4	60.8	155.8	318.4	73.9	170.7	333.6
Bproj/Bmin(%)	88.1	288.1	687.1	109.3	316.9	720.1	134.0	345.8	751.0
Bproj/Bref(%)	26.2	85.1	202.6	32.4	93.7	211.5	39.6	102.2	221.1
%Bincrease		71			79			86	
%>Bmin		93			96			98	

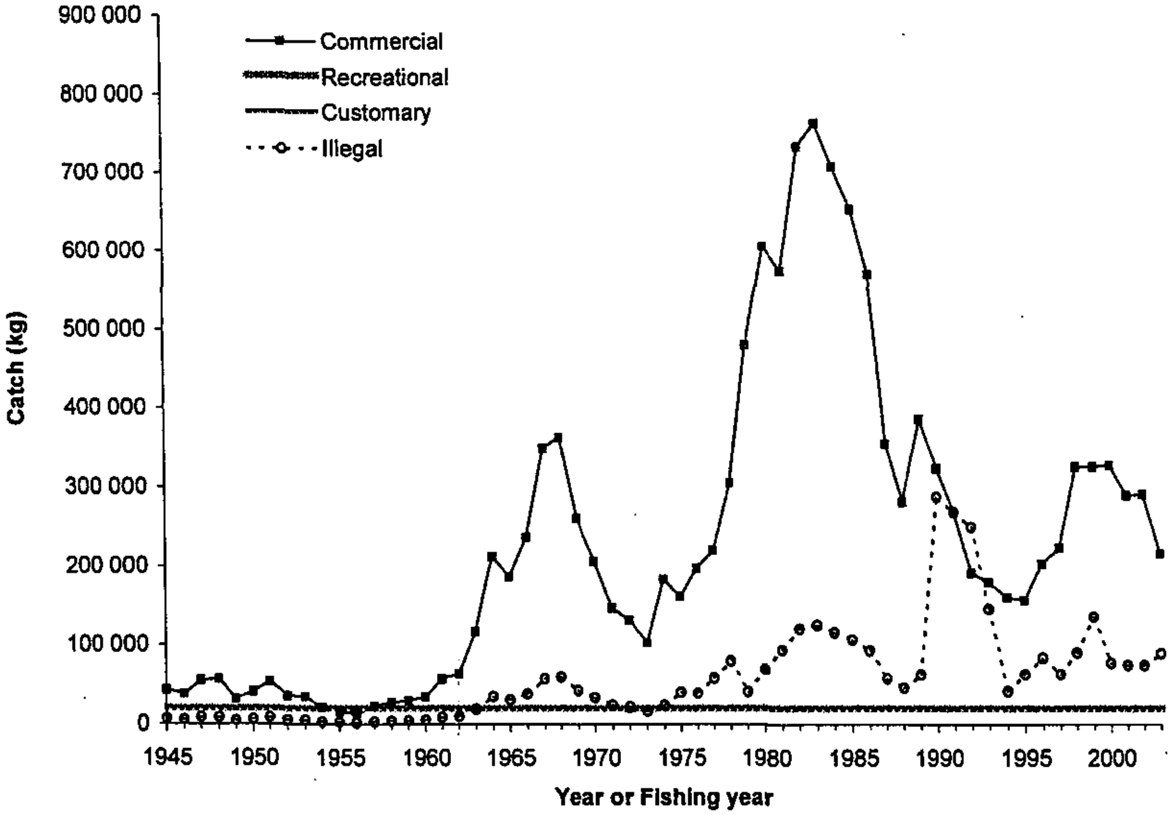


Figure 1: **Annual CRA 3 catches (kg) by user category.**

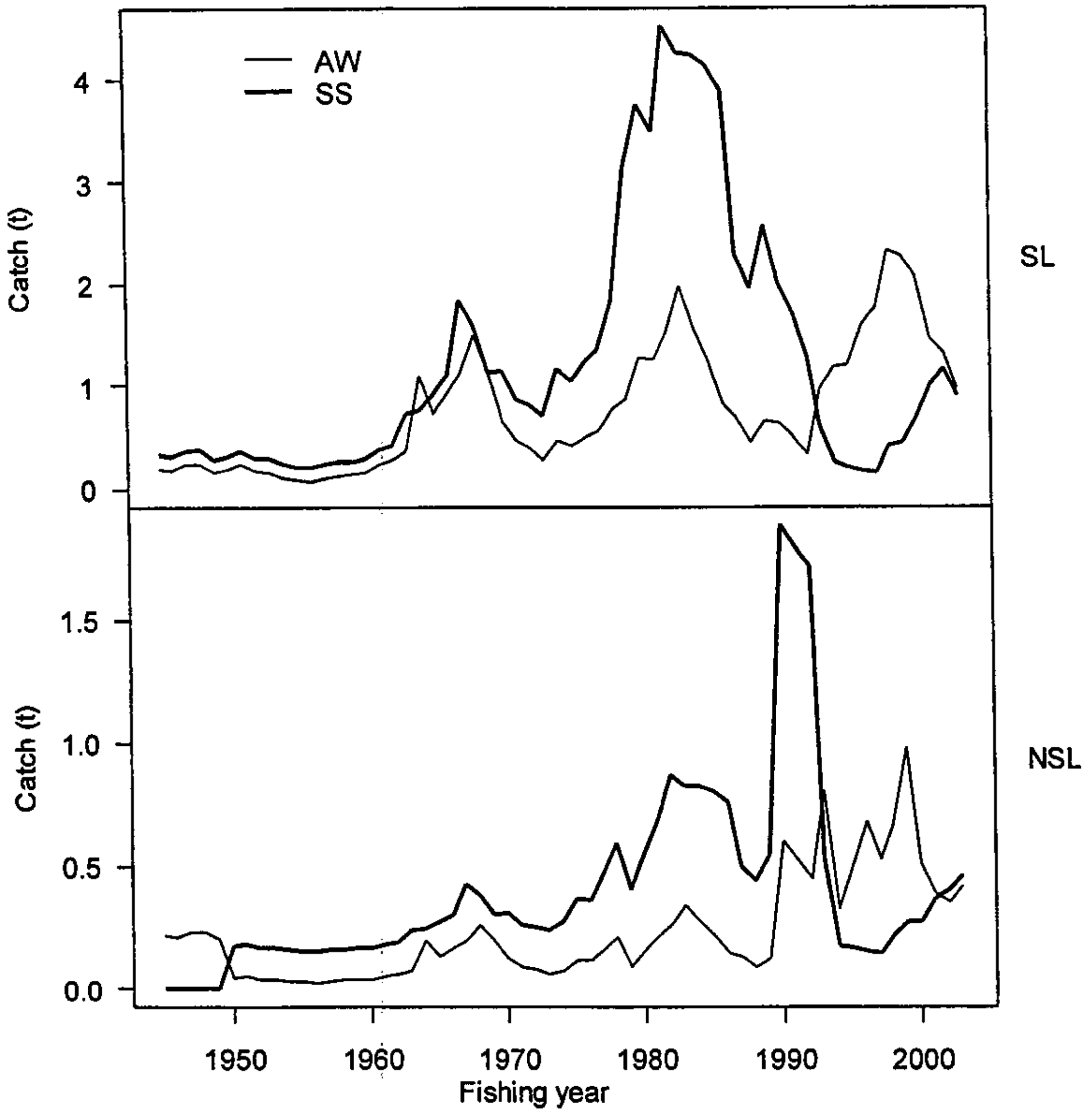


Figure 2: **CRA 3 catches: upper: SL (size-limited) and lower: NSL (non-size-limited) catches by season (AW: autumn-winter; SS: spring-summer).**

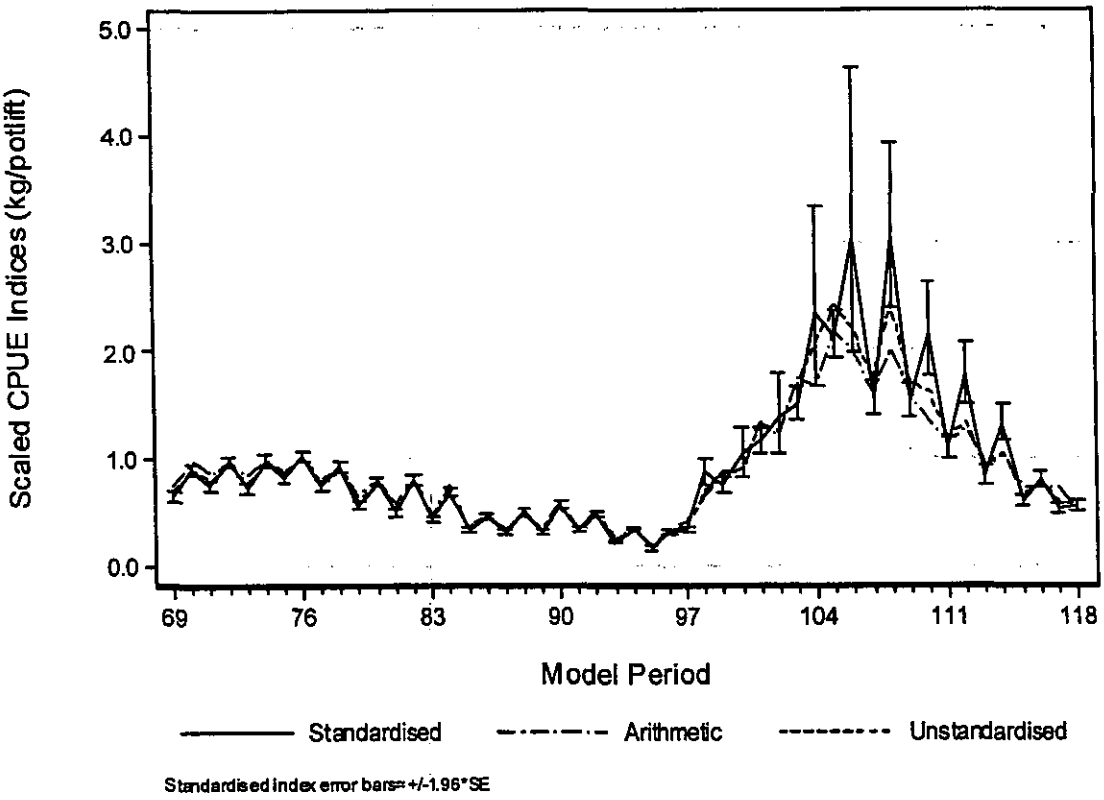


Figure 3: Standardised CPUE used for the CRA 3 assessment. Period 69 is AW 1979; period 118 is SS 2003.

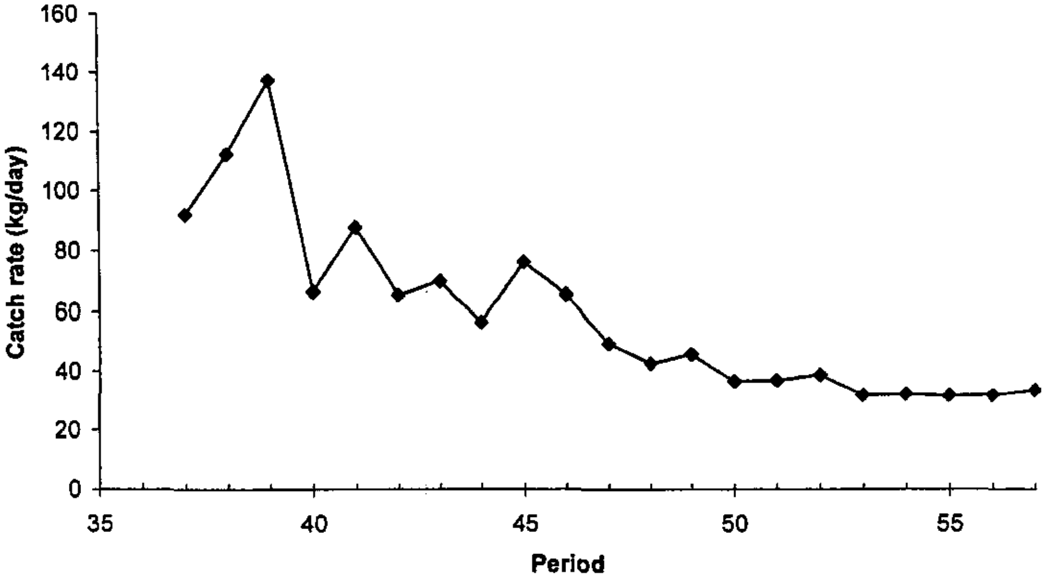


Figure 4: Historical catch rate (CR) by period for CRA 3. Period 37 is AW 1963; period 57 is AW 1973.

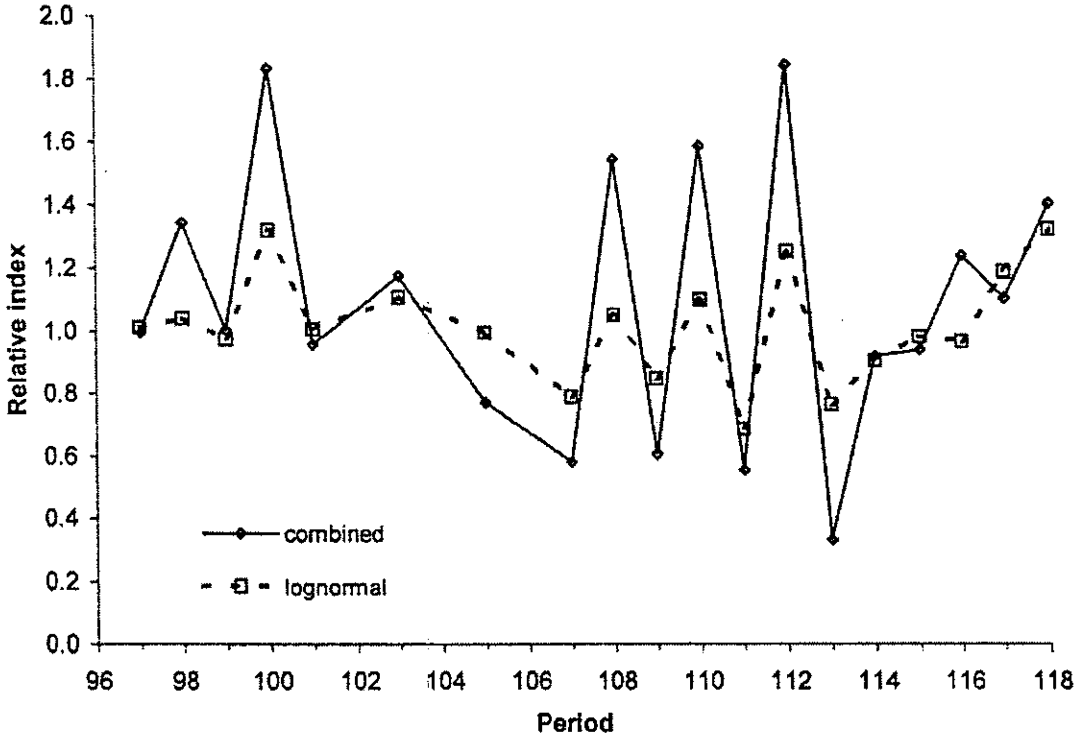


Figure 5: Pre-recruit index (PRI) by period for CRA 3. The dashed line shows the lognormal model results, used in the assessment, and the solid line shows the experimental combined model. Period 97 is AW 1993; period 118 is SS 2003.

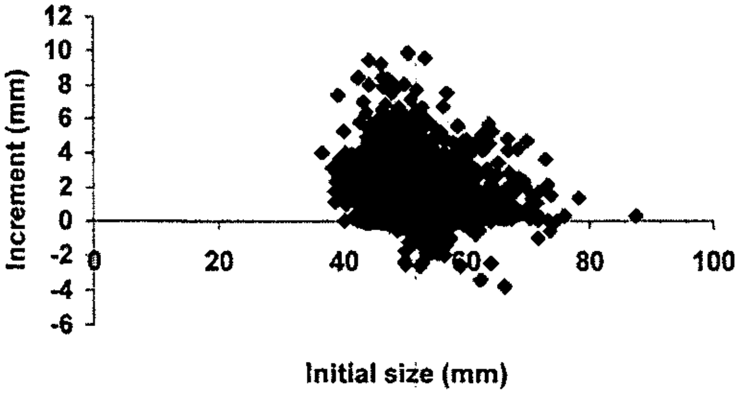


Figure 6: Combined CRA 3 and CRA 5 tag-recapture data: growth increment per period for males plotted against size at release.

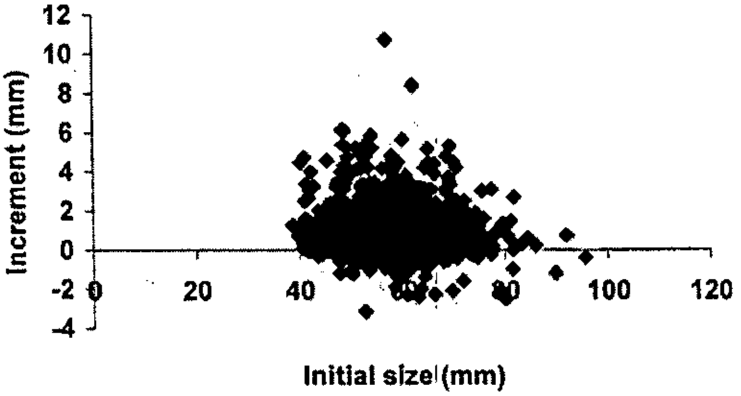
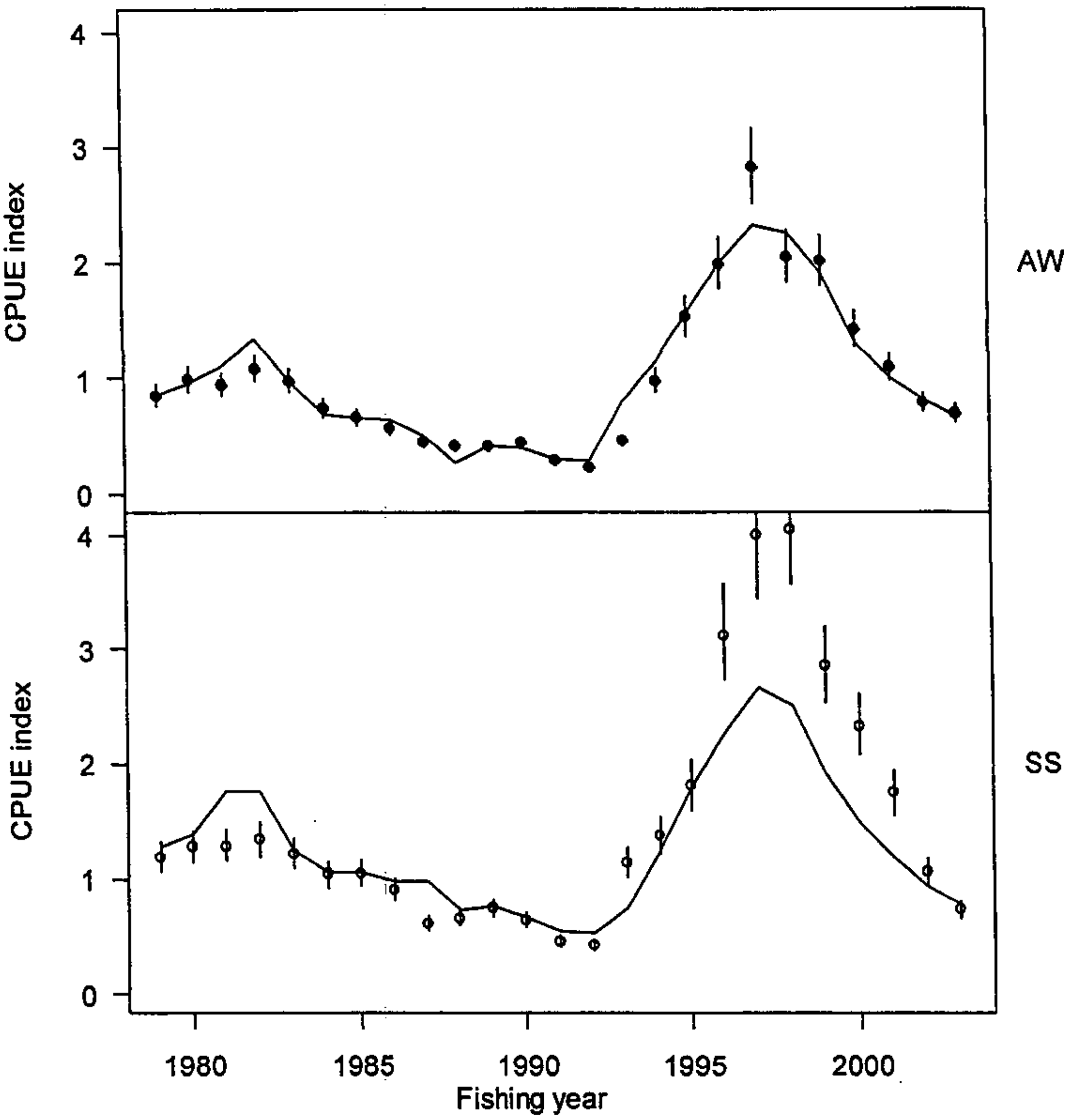
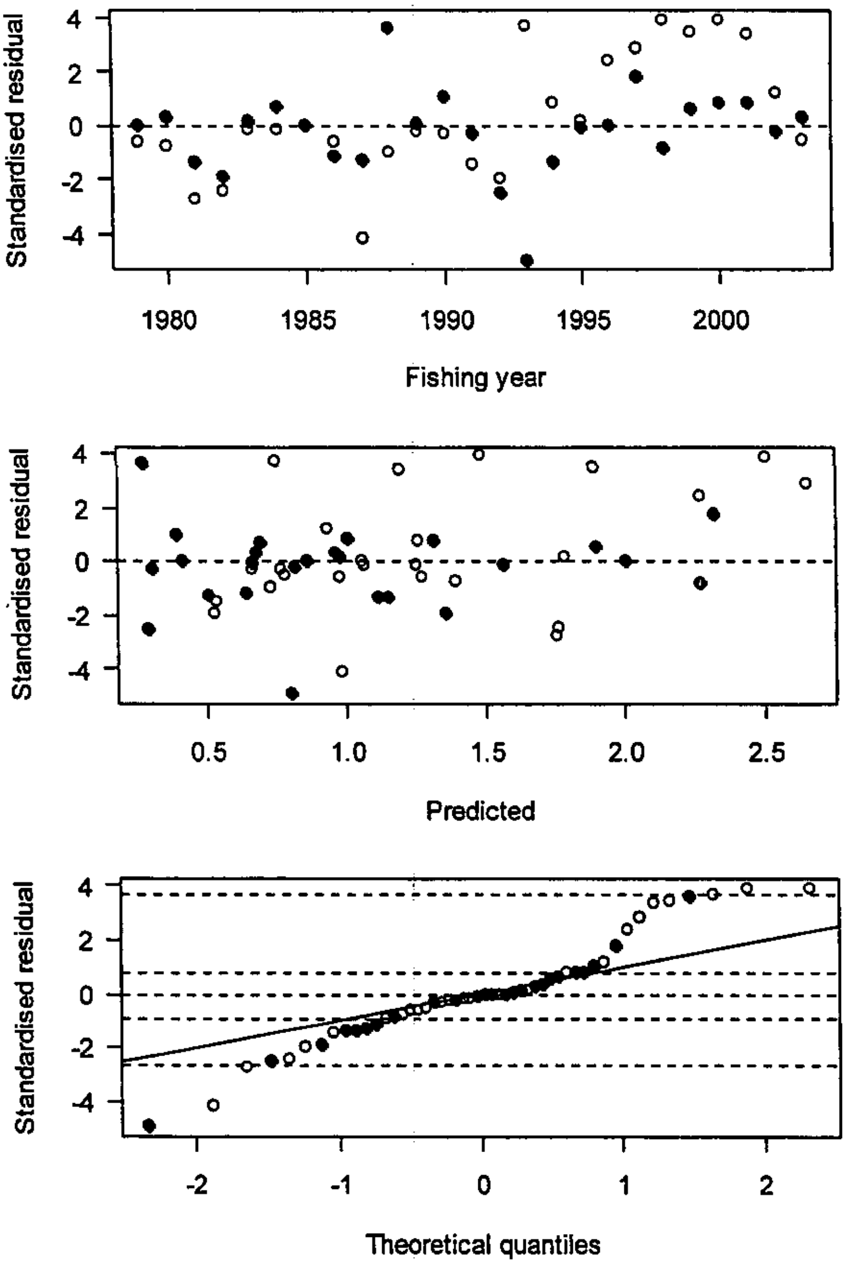


Figure 7: Combined CRA 3 and CRA 5 tag-recapture data: growth increment per period for females plotted against size at release.



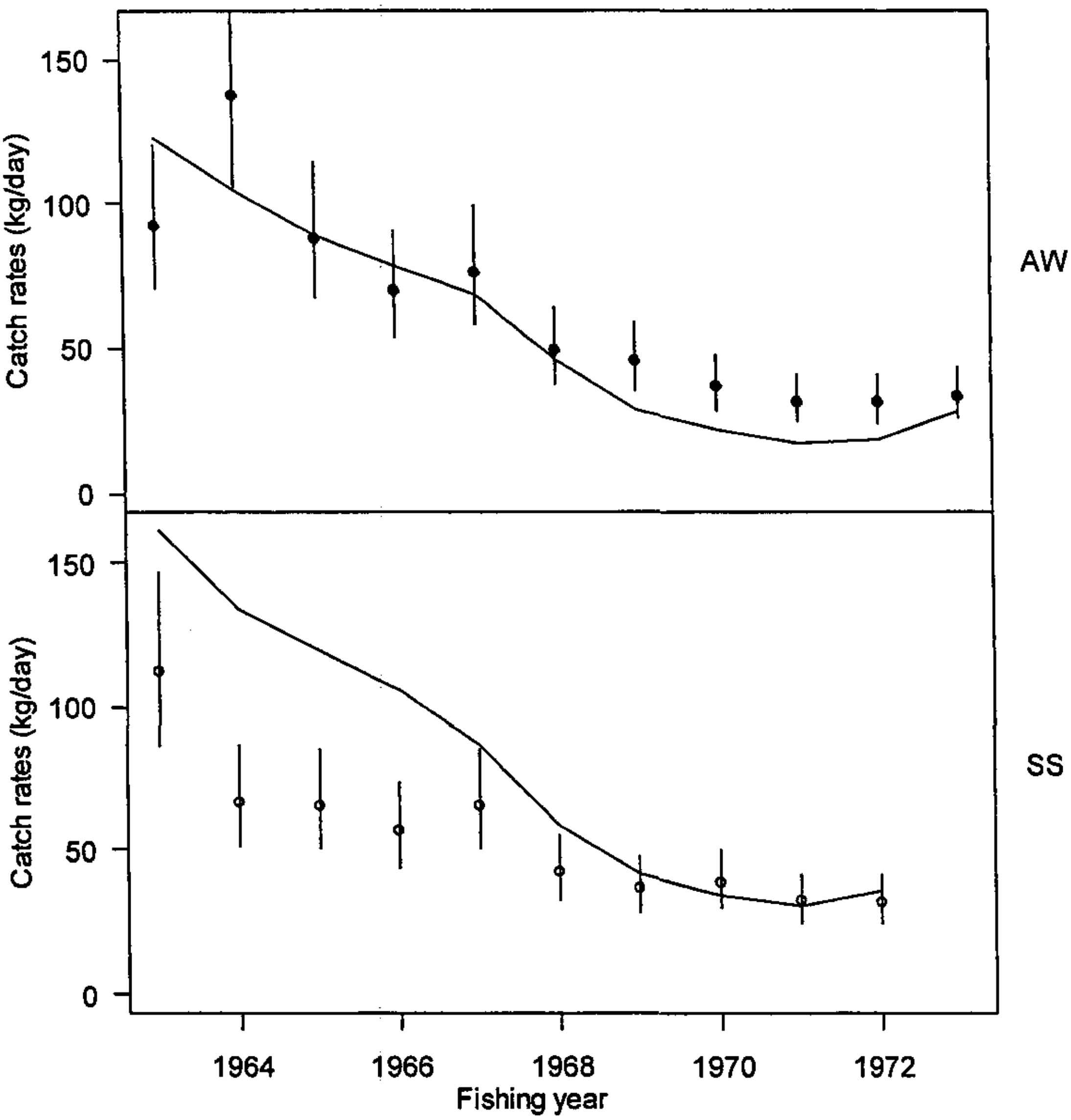
001 : Observed and predicted for CPUE fits.

Figure 8: Predicted (line) and observed (circles with one standard error, taking all sources of variability into account) standardised CPUE index by season from the base case MPD results for CRA 3.



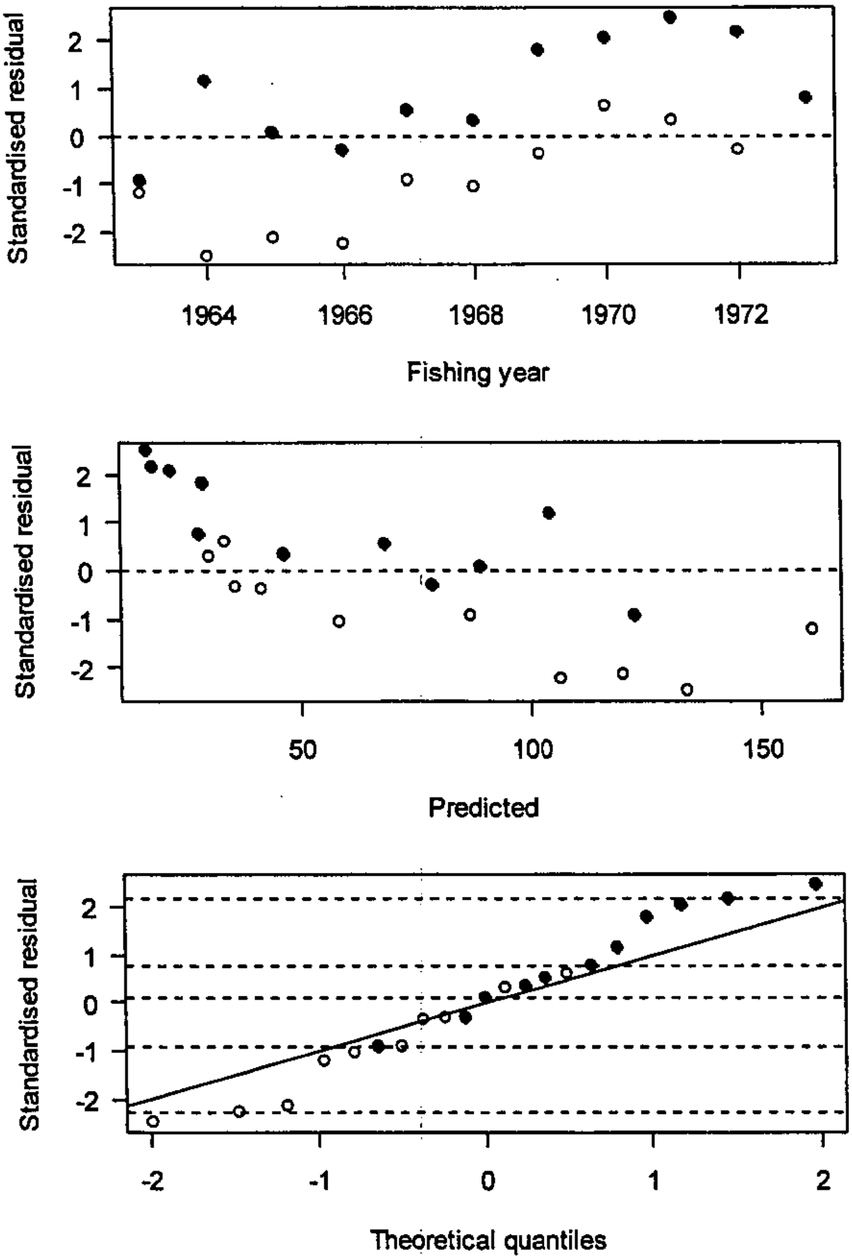
001 : Standardised residual for CPUE fits

Figure 9: Normalised residuals of predicted CPUE index from the base case MPD results for CRA 3, plotted by fishing year (upper panel) and by predicted CPUE index (centre panel), and the quantile-quantile plot (lower panel). Closed circles, AW season; open circles, SS season.



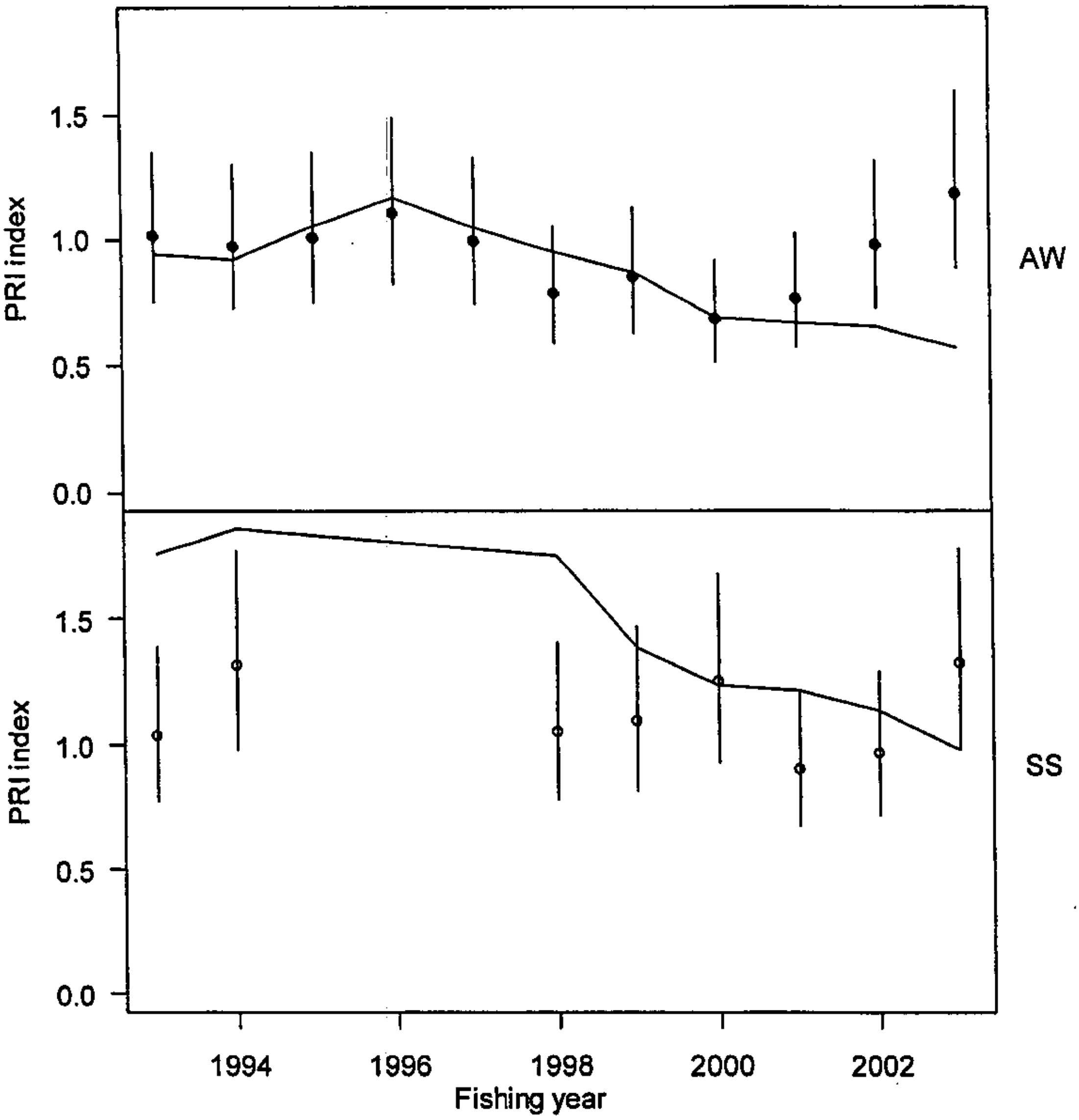
001 : Observed and predicted for CR fits.

Figure 10: Predicted (solid line) and observed (circles with one standard error, taking all sources of variability into account) catch rate (CR) by season from the base case MPD results for CRA 3.



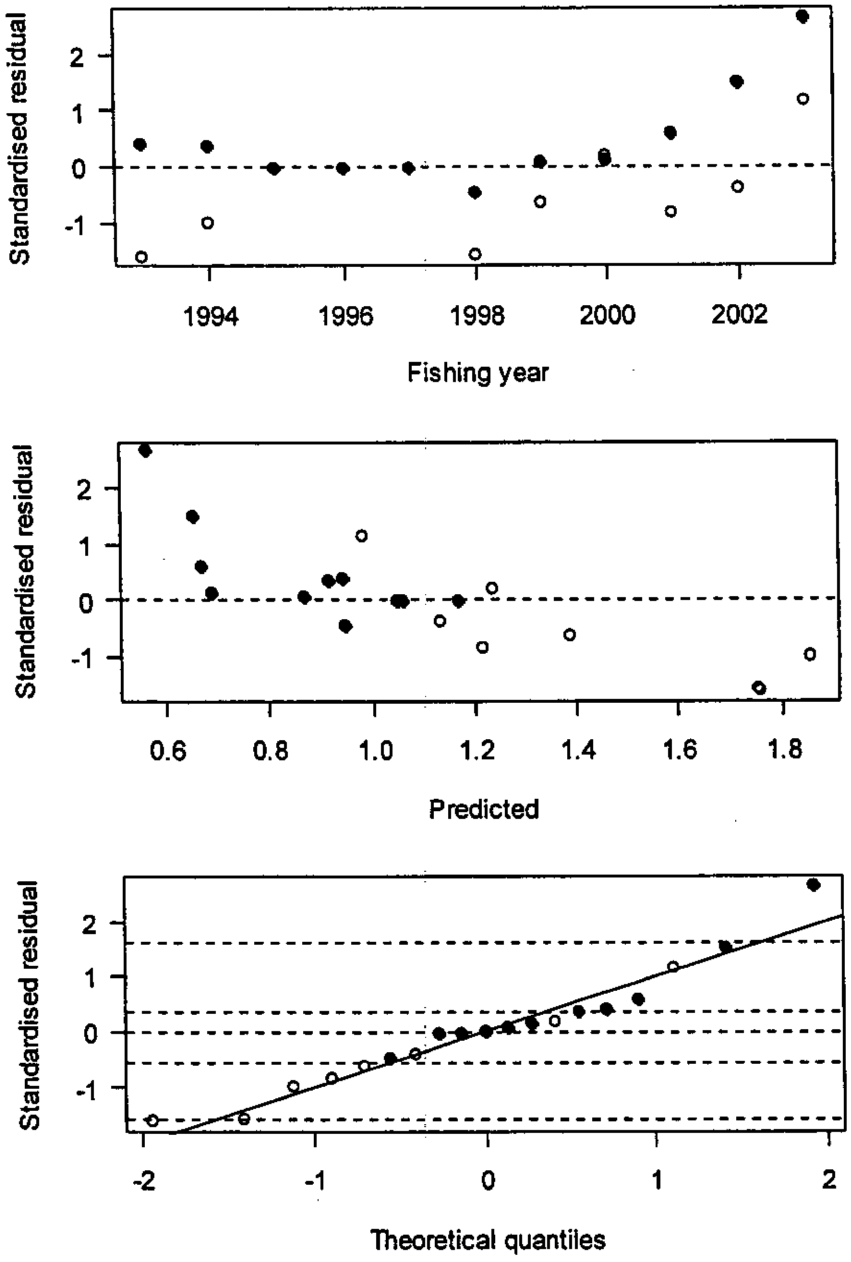
001 : Standardised residual for CR fits

Figure 11: Normalised residuals of predicted CR index from the base case MPD results for CRA 3, plotted by fishing year (upper panel) and by predicted CR index (centre panel), and the quantile-quantile plot (lower panel). Closed circles, AW season; open circles, SS season.



001 : Observed and predicted for PRI fits.

Figure 12: Predicted (solid line) and observed (circles with one standard error, taking all sources of variability into account) pre-recruit index (PRI) by season from the base case MPD results for CRA 3.



001 : Standardised residual for PRI fits

Figure 13: Normalised residuals of predicted PRI index from the base case MPD results for CRA 3, plotted by fishing year (upper panel) and by predicted PRI index (centre panel), and the quantile-quantile plot (lower panel). Closed circles, AW season; open circles, SS season.

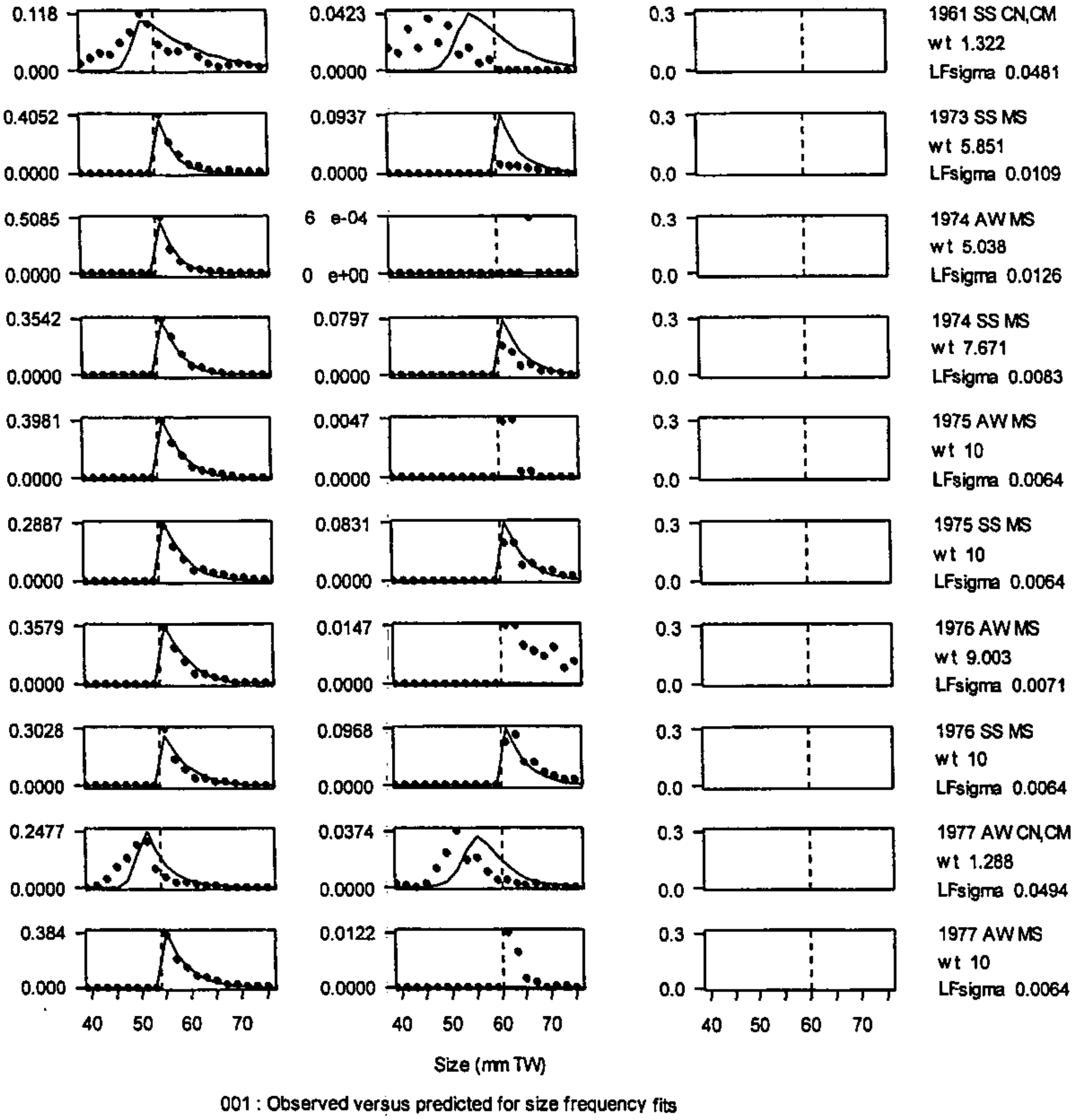
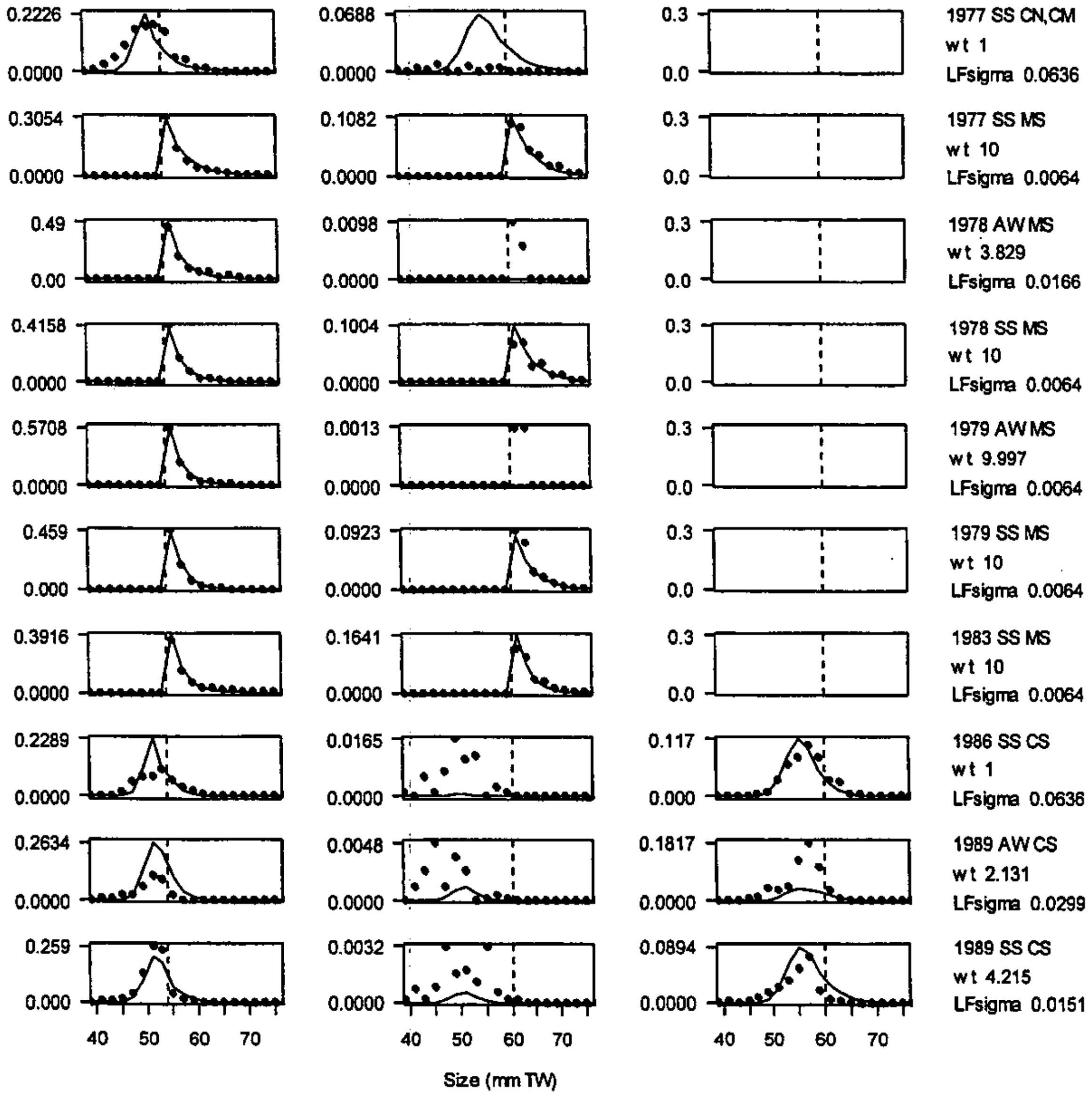


Figure 14: The CRA 3 base case MPD fit to the proportion-at-length data, plotted by year and season, sex category and data source type. The left column shows males, the centre immature females, and the right mature females. Note that y-axis scales are unique to each diagram. AW, autumn-winter; SS, spring-summer; MS, market sampling; LB, log book data; CS, catch sampling data; wt (= κ_t), relative weight given to each data set. *The dotted vertical line is the current summer MLS.*



001 : Observed versus predicted for size frequency fits

Figure 14: continued.

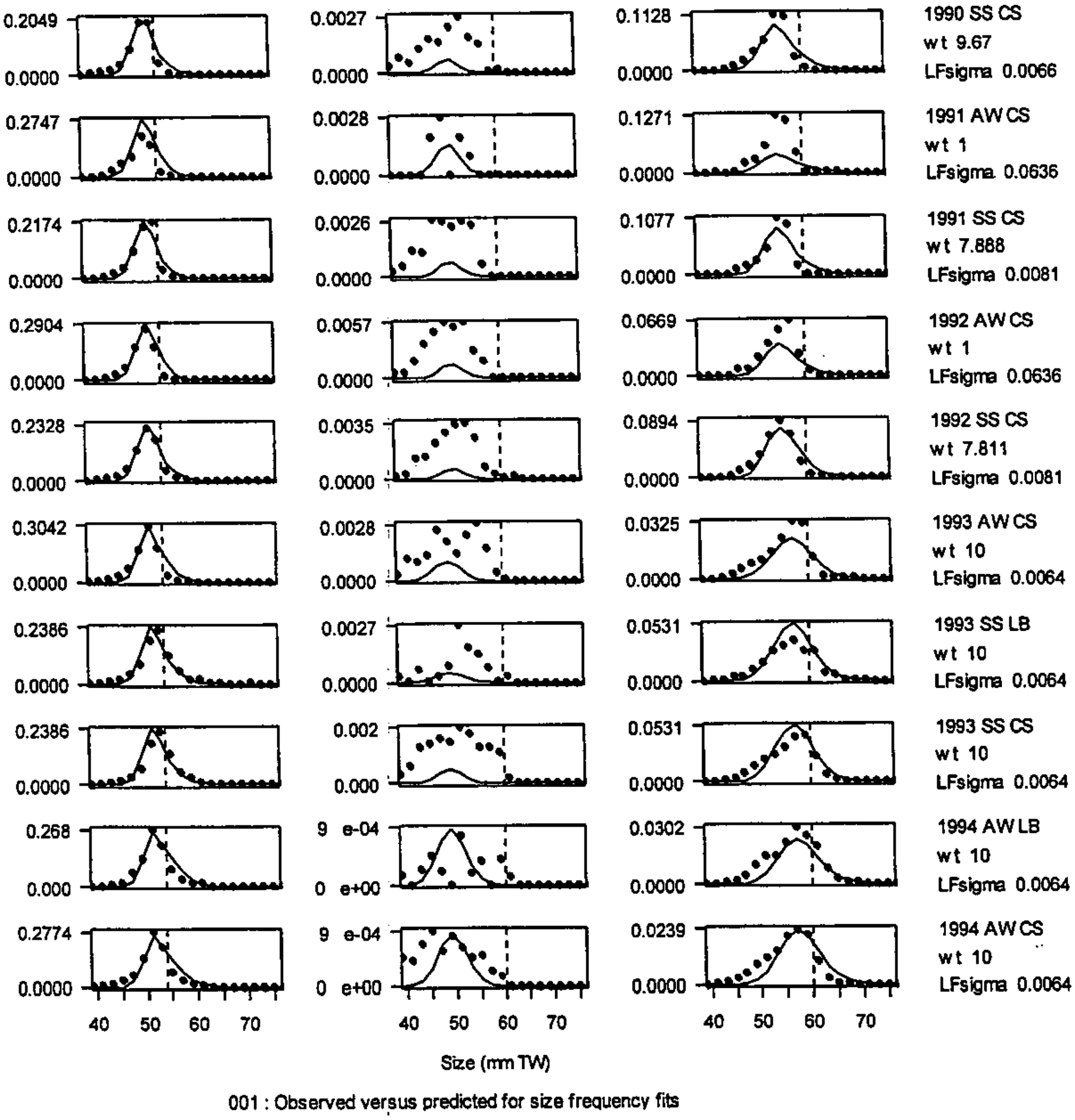


Figure 14: continued.

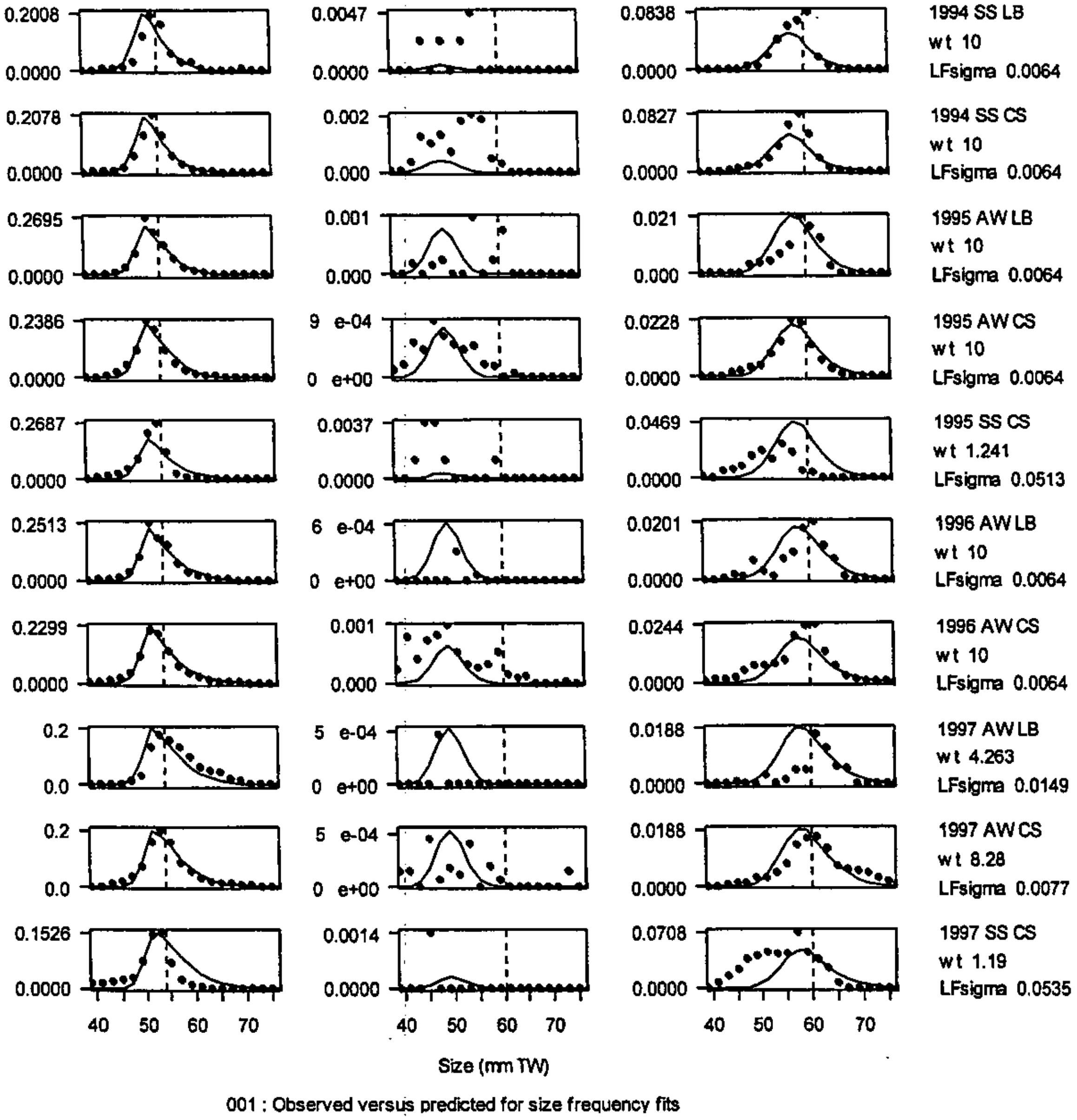
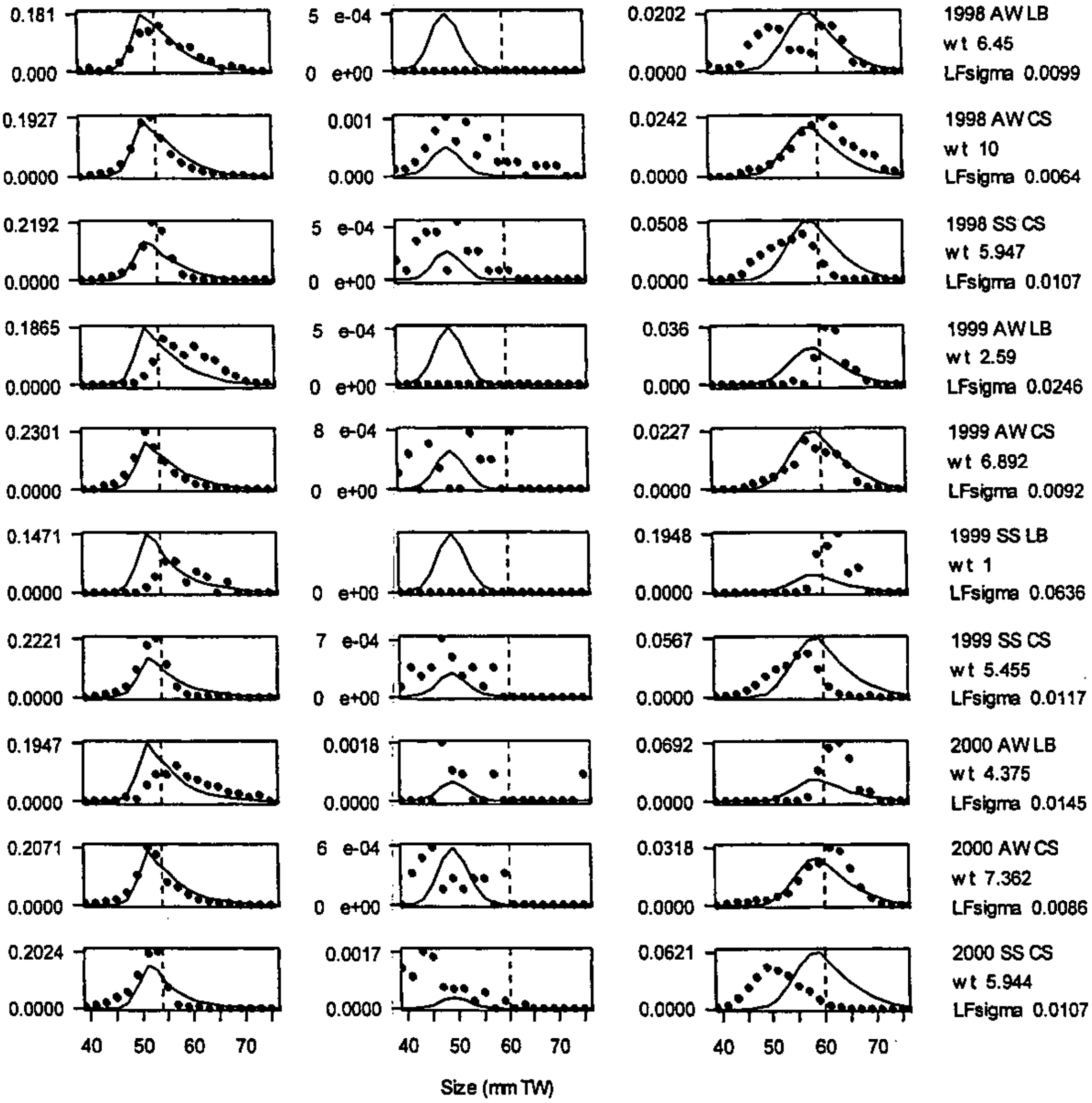


Figure 14: continued.



001 : Observed versus predicted for size frequency fits

Figure 14: continued.

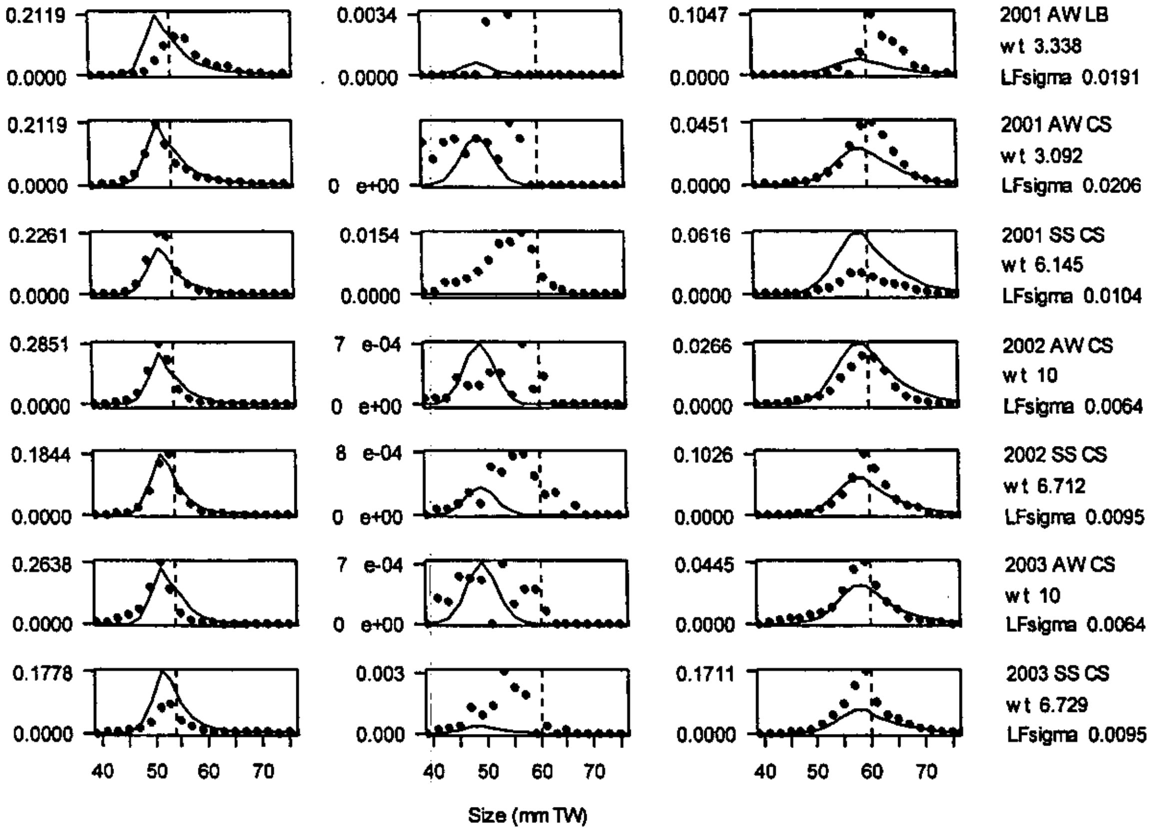
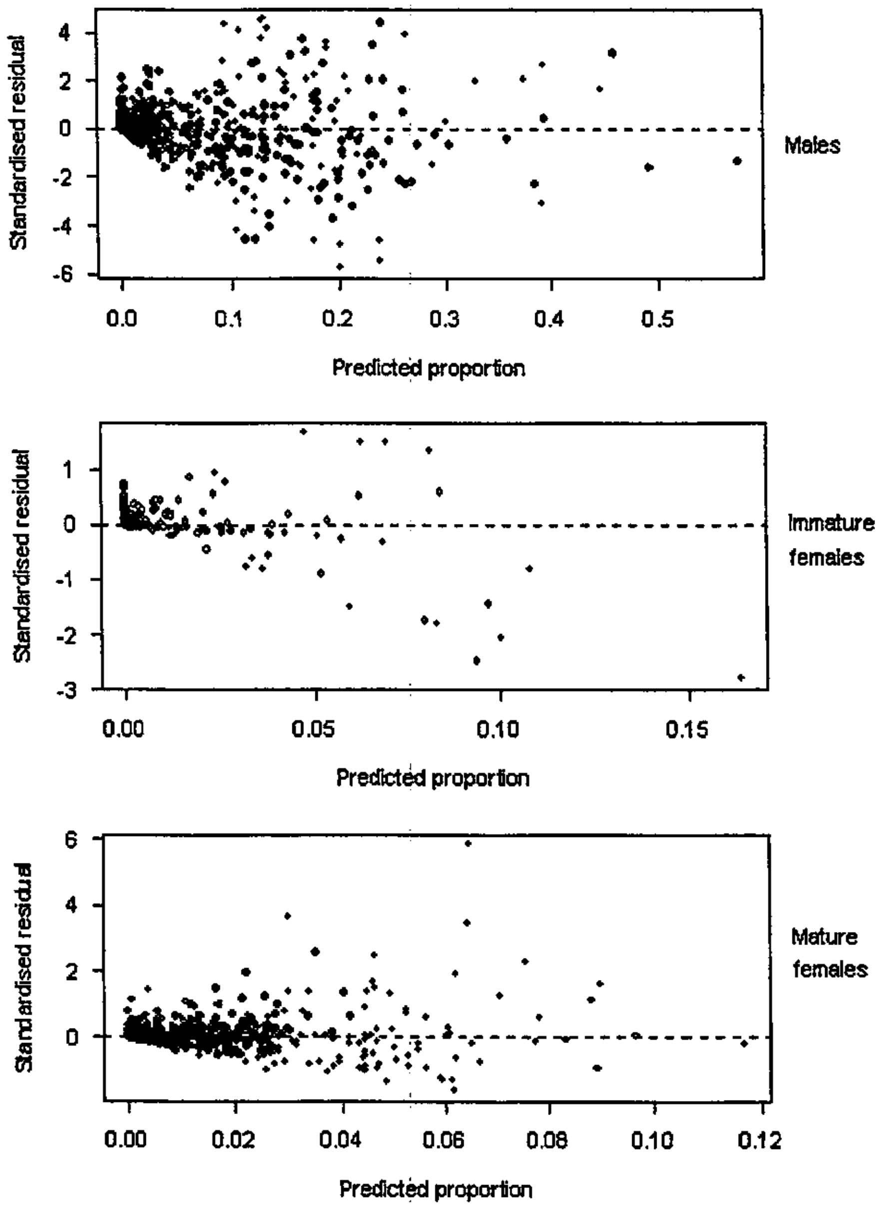
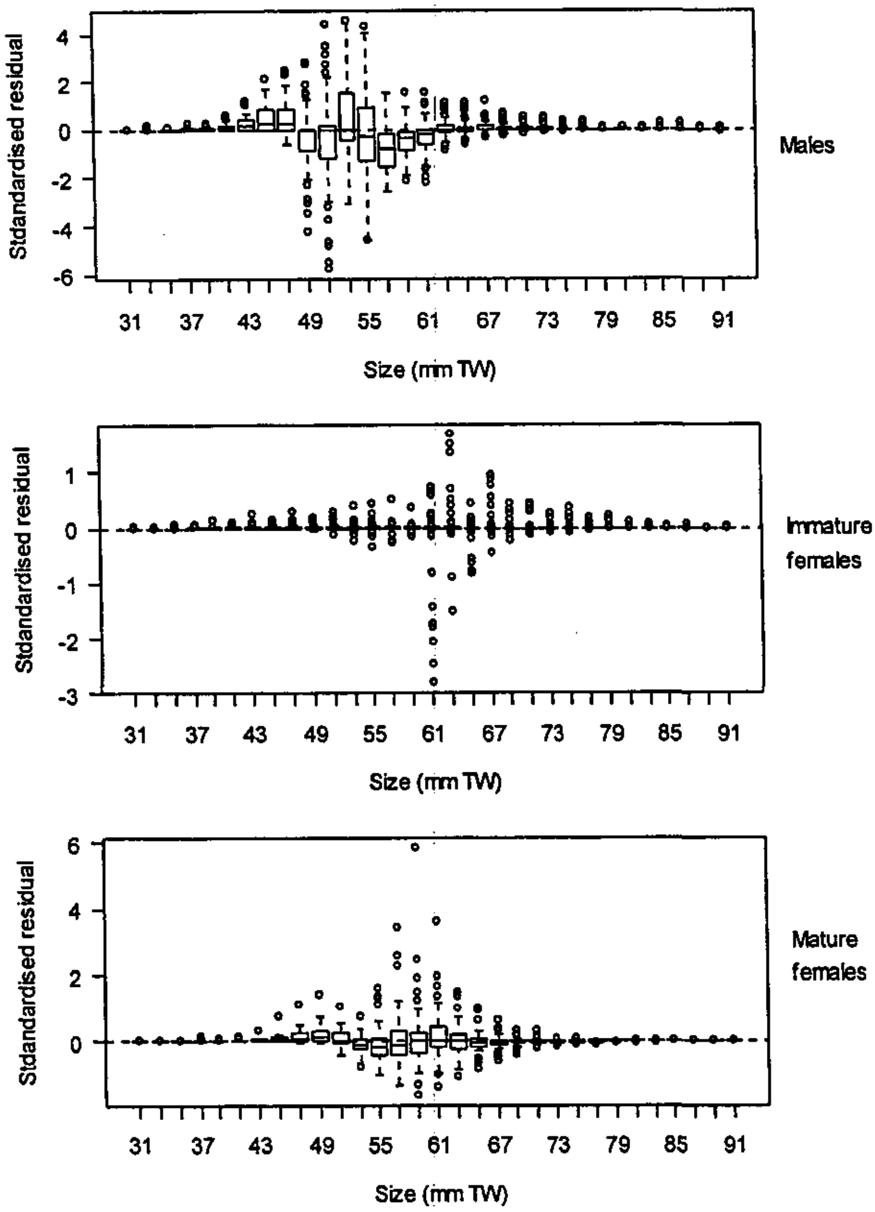


Figure 14: continued.



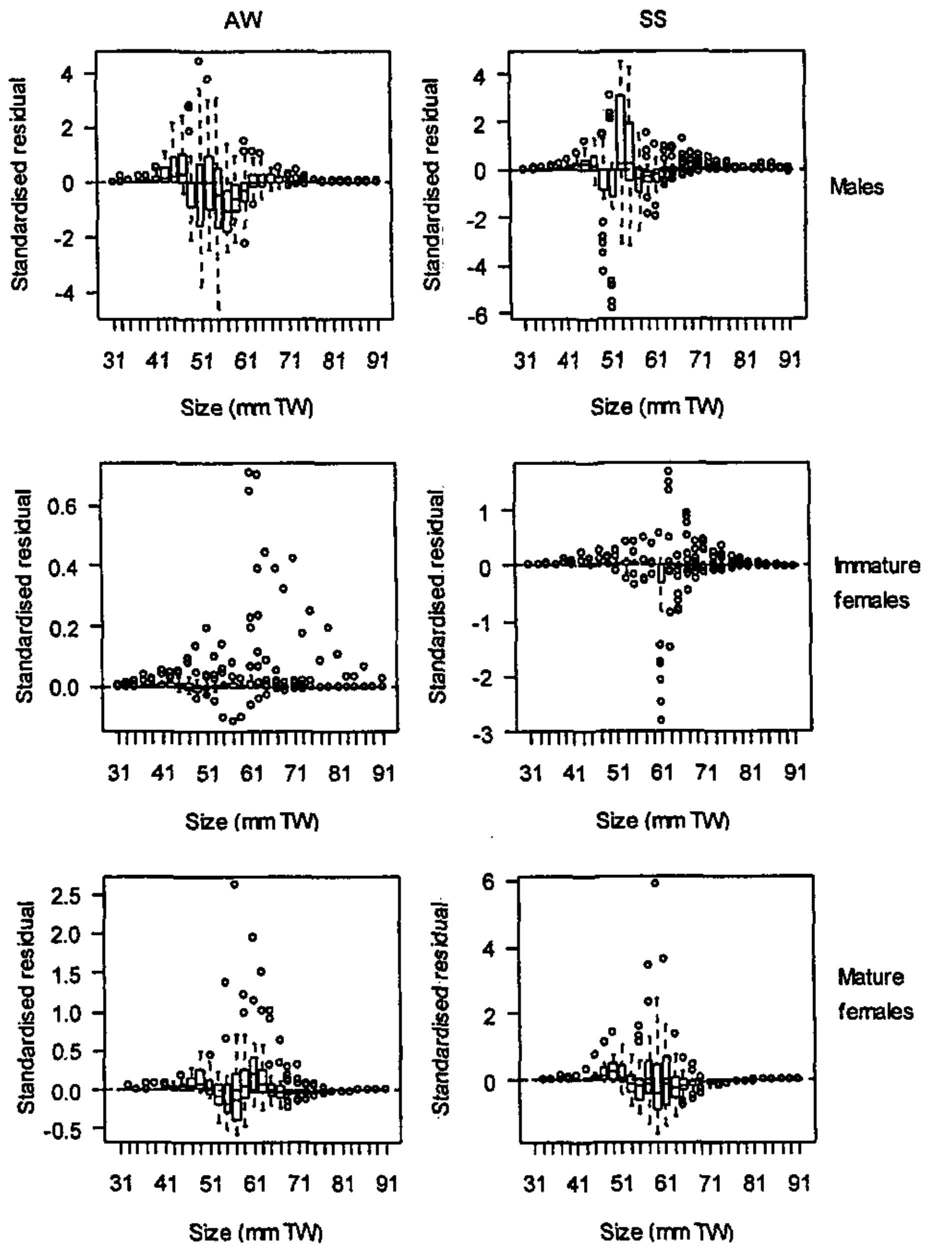
001 : Standardised residual versus predicted proportion for size frequency fits
Closed circles: AW; Open circles: SS

Figure 15: Normalised residuals from the base case CRA 3 MPD fits to proportions-at-length, plotted against predicted proportions-at-length for the three sex categories.



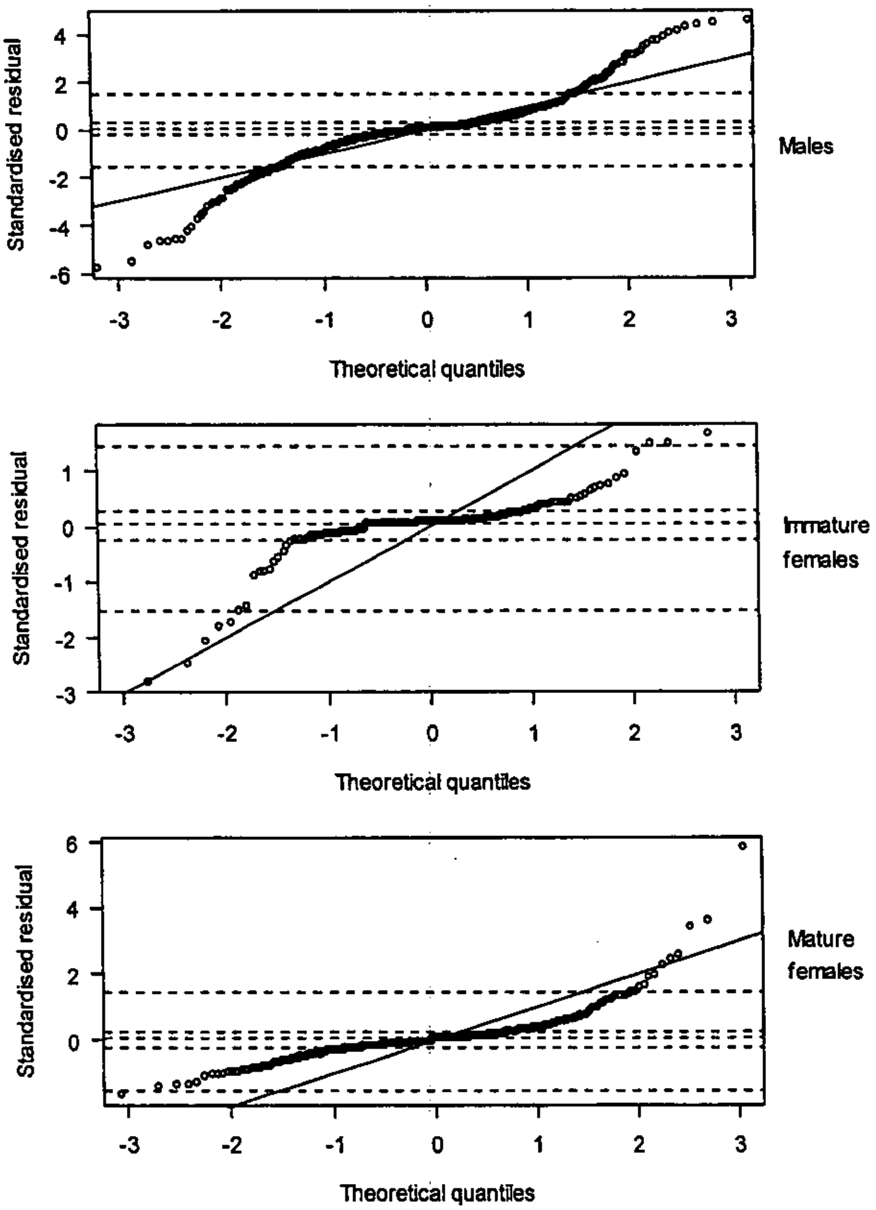
001 : Box plots of standardised residuals of LF for each sex and size class

Figure 16: Normalised residuals from the base case CRA 3 MPD fits to proportions-at-length plotted against length for the three sex categories. The box plots show the median as a horizontal line, the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles and other points indicate outliers.



001 : Box plots of standardised residuals for each sex and size class

Figure 17: Normalised residuals from the base case CRA 3 MPD fits to proportions-at-length plotted against length by season for the three sex categories. Left panels are the AW season, right panels are the SS season. The box plots show the median as a horizontal line, the box encloses the central 50% of the data, whiskers indicate the 5th and 95th percentiles and other points indicate outliers.



001 : Quantile-quantile plots for size frequencies by sex
Horizontal lines are 5, 25, 50, 75, 95 percent of residuals

Figure 18: Quantile-quantile plot of normalised residuals from the base case CRA 3 MPD fits to proportions-at-length for the three sex categories.

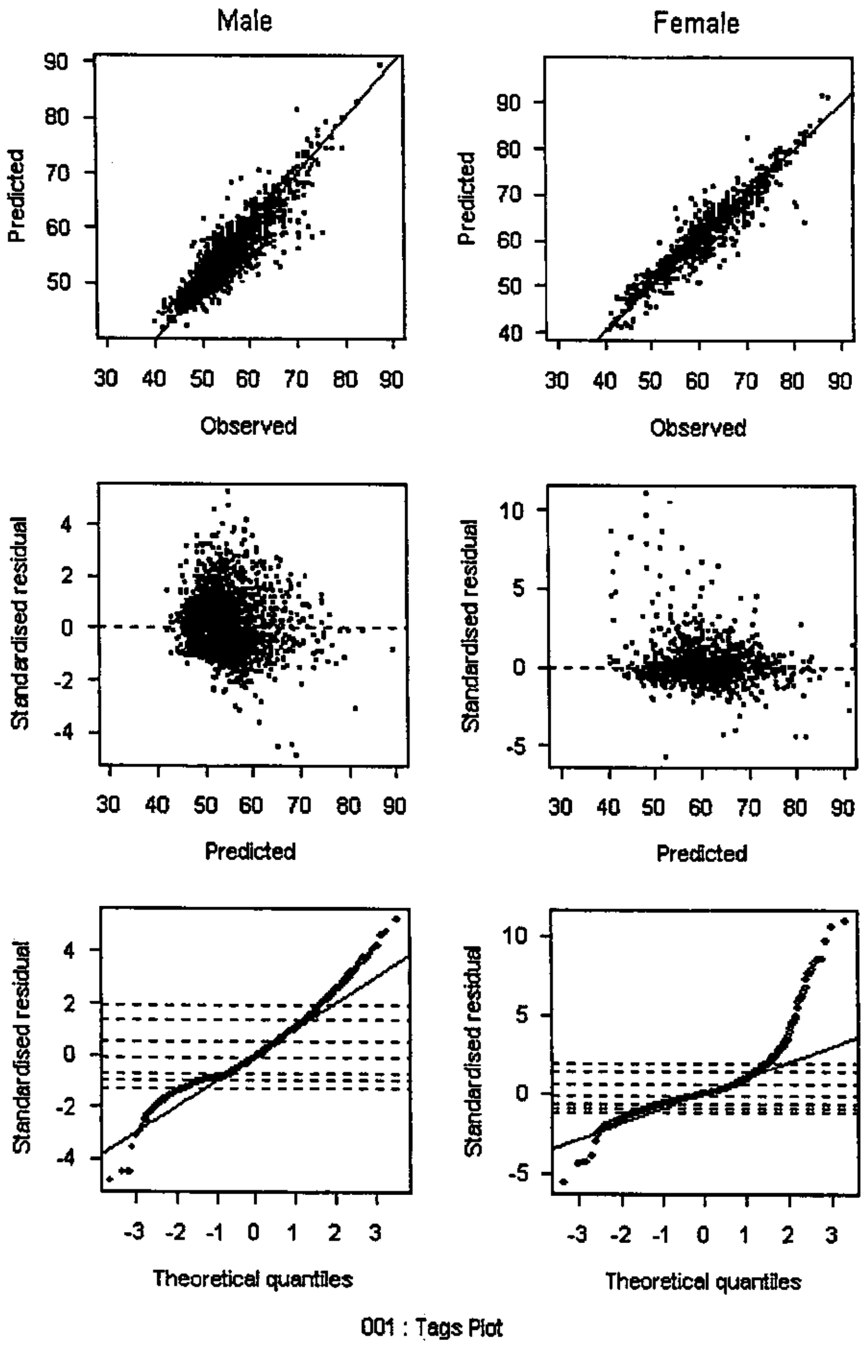


Figure 19: Predicted and observed size at recapture from the base case CRA 3 MPD fit to the tag-recapture data (top panels); normalised residuals plotted against predicted size at recapture (middle panels); quantile-quantile plots of the normalised residuals (bottom panels). Left panels are males and right panels are females.

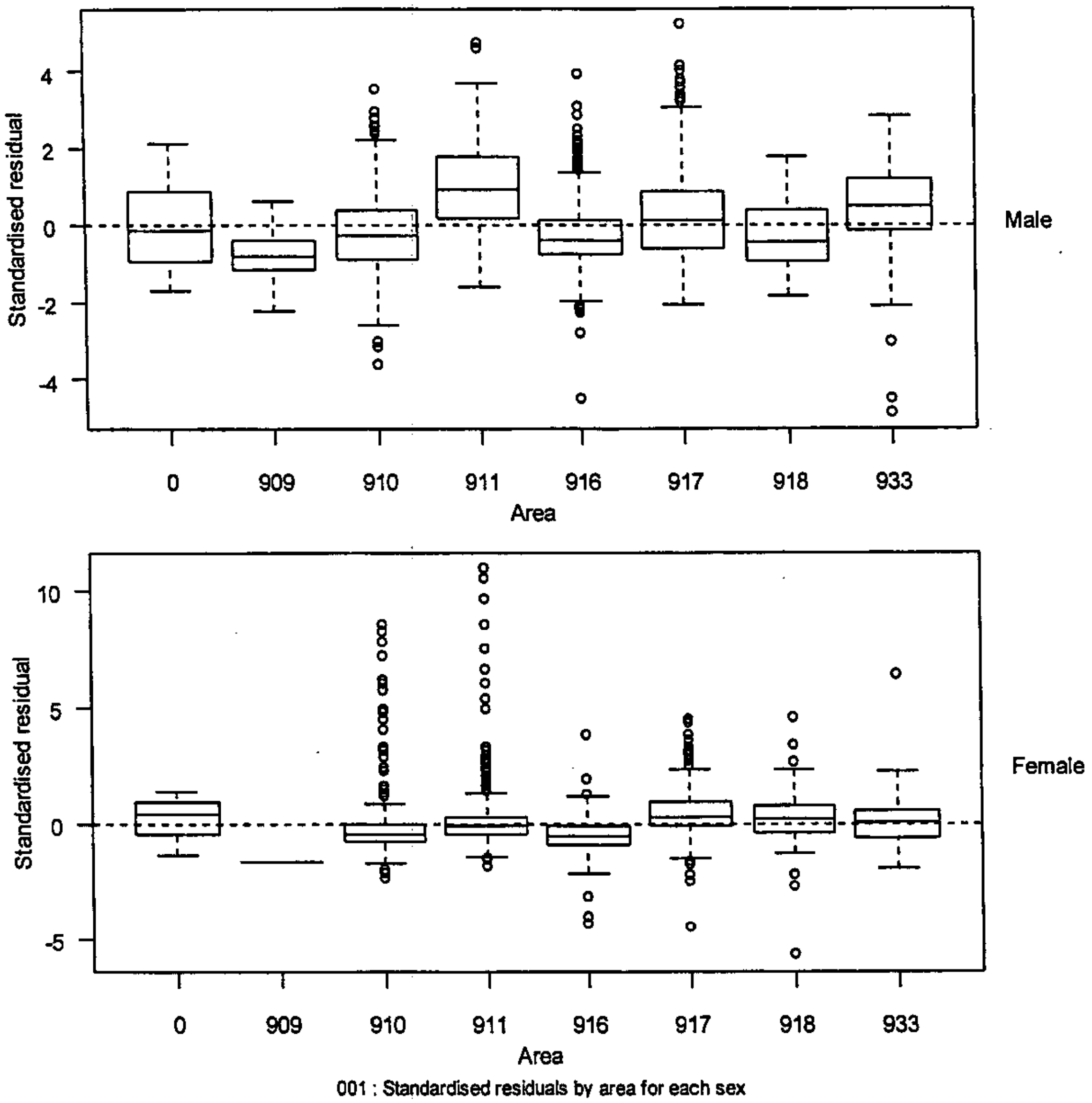


Figure 20: Box plots of the residuals from the base case CRA 3 MPD fit to tag-recapture data, plotted by area of release.

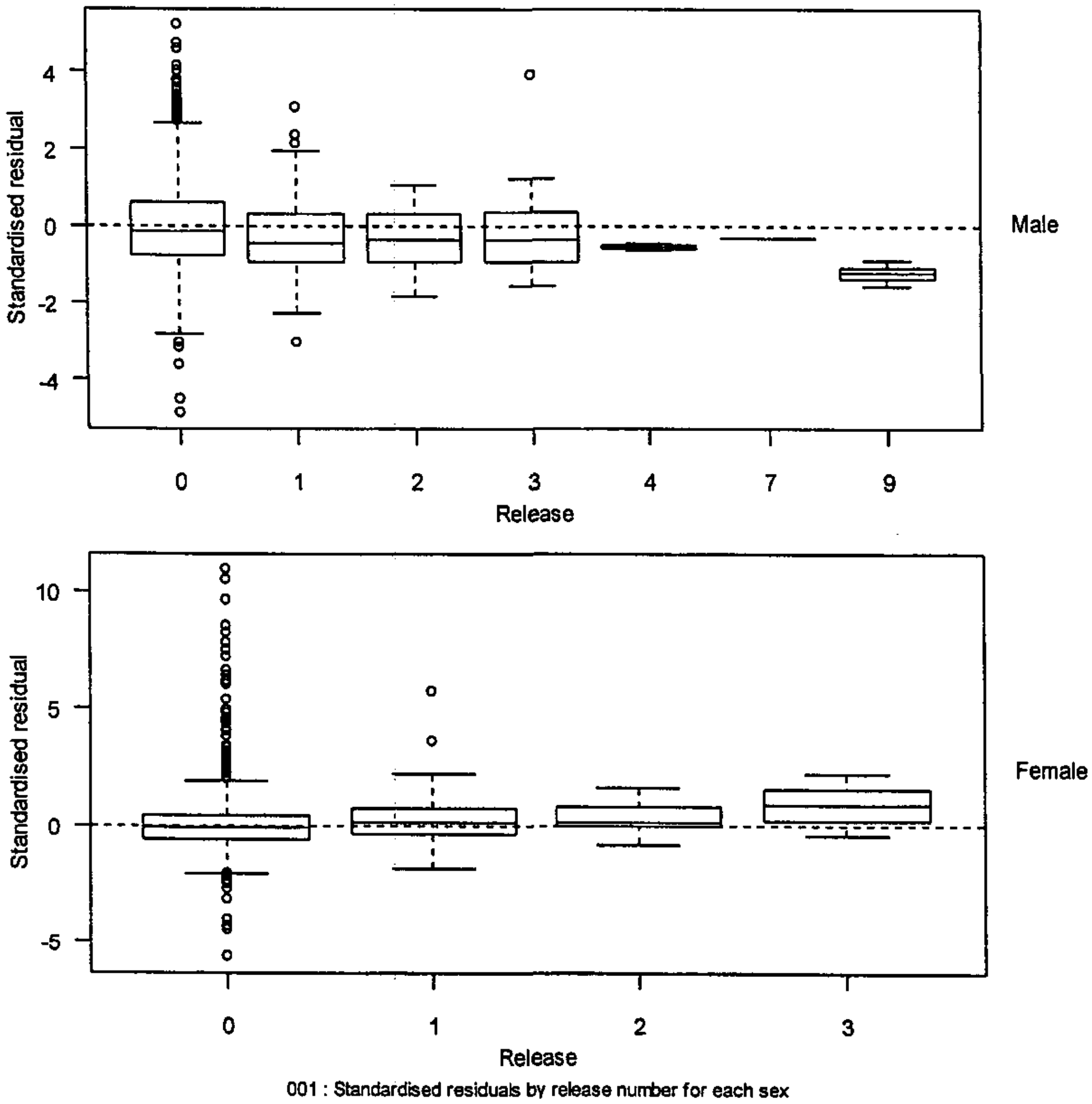


Figure 21: Box plots of the residuals from the base case CRA 3 MPD fit to tag-recapture data, plotted by the number of re-releases for males and females.

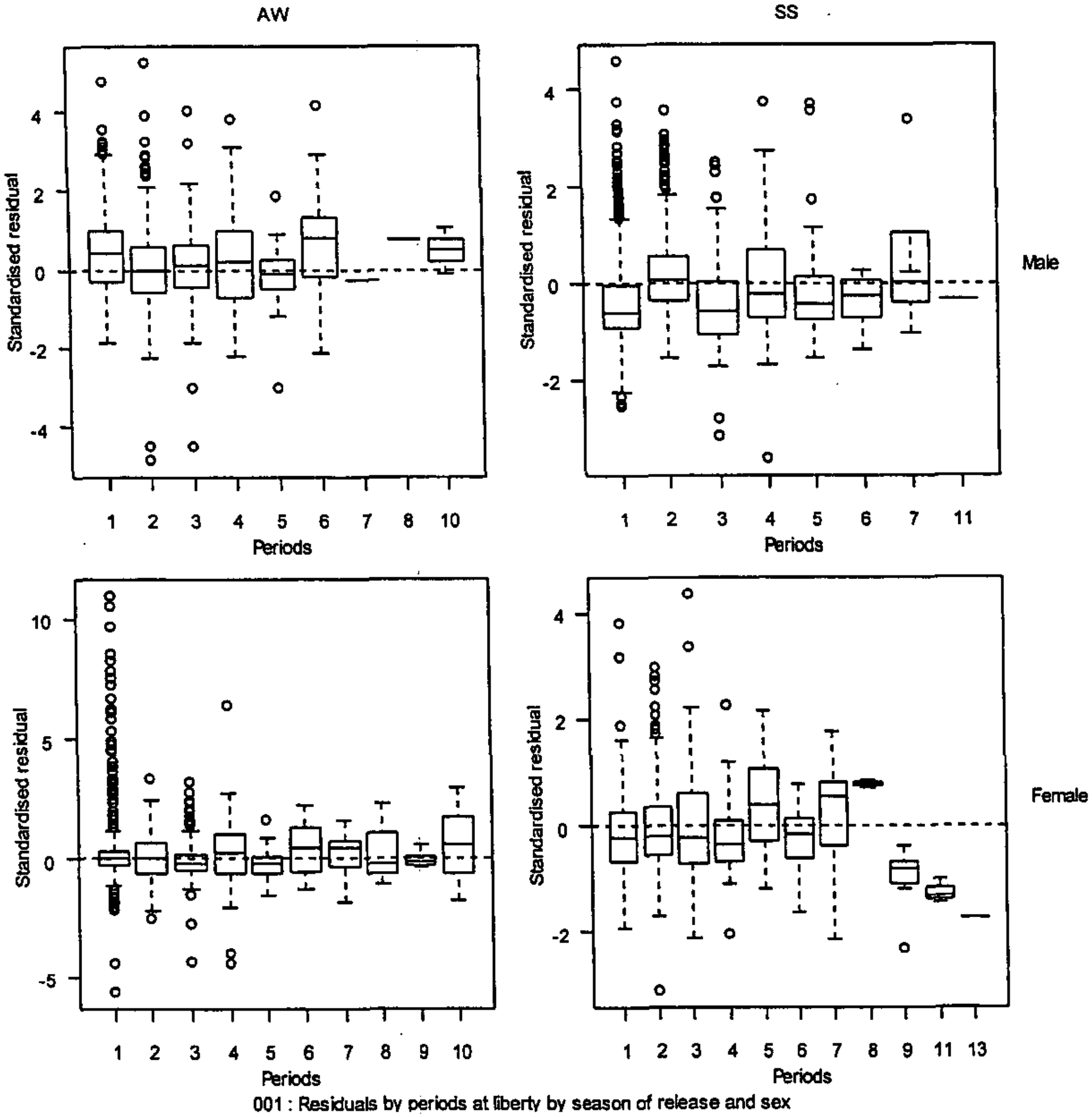


Figure 22: Box plots of residuals from the base case CRA 3 MPD fit to tag-recapture data, plotted by the number of periods at liberty and by season of release.

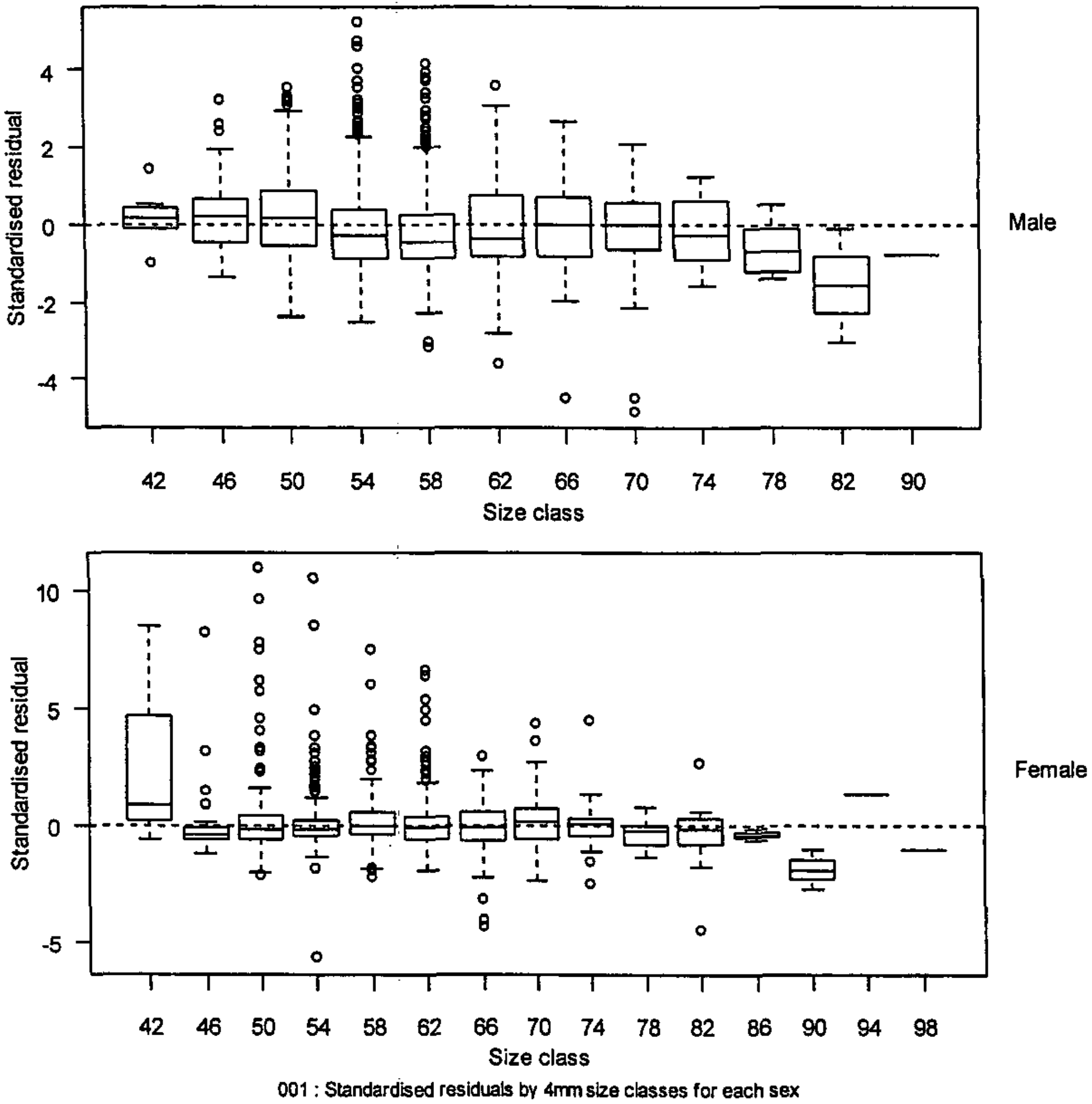


Figure 23: Box plots of residuals from the base case CRA 3 MPD fit to tag-recapture data, plotted by initial size.

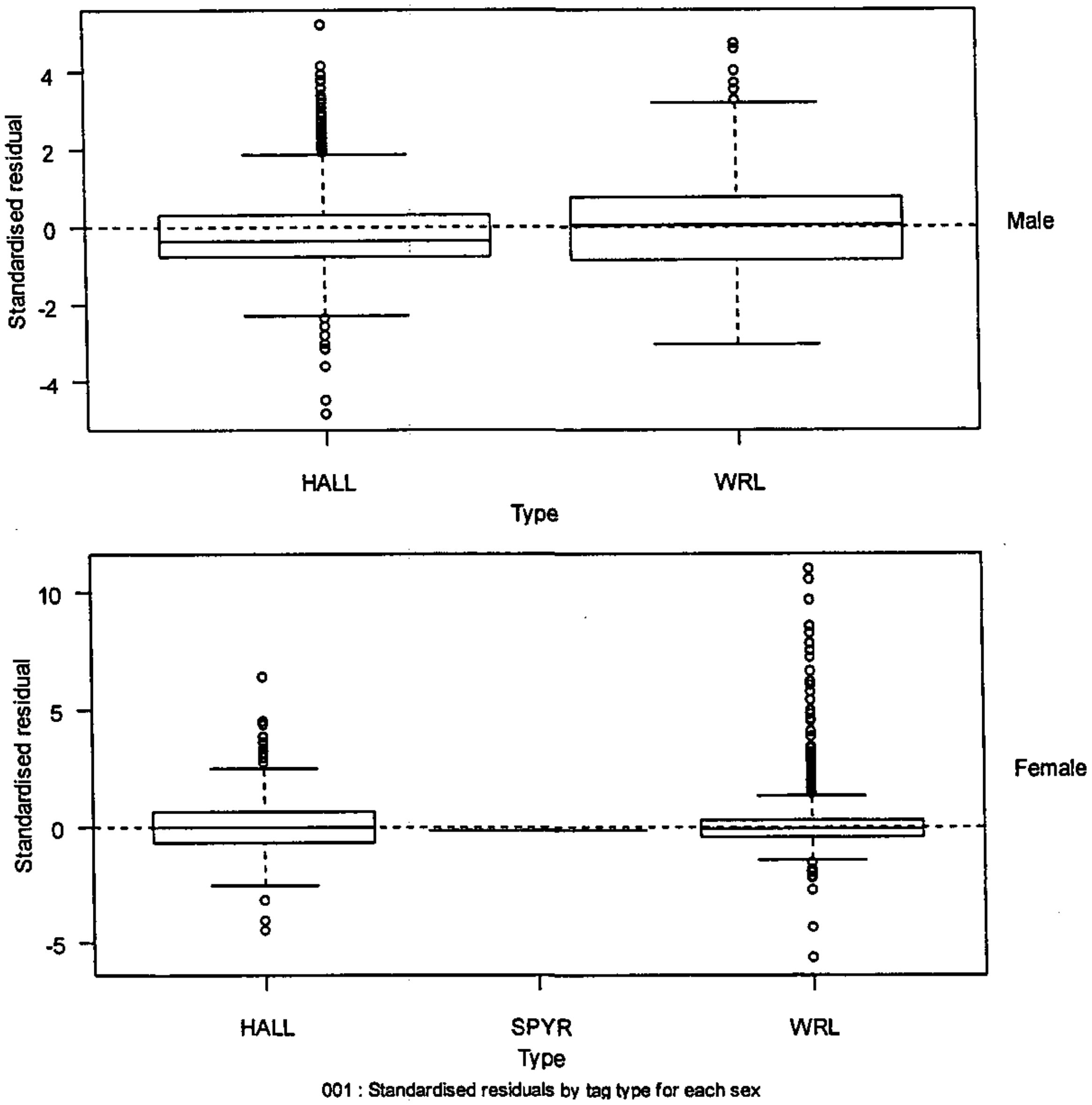
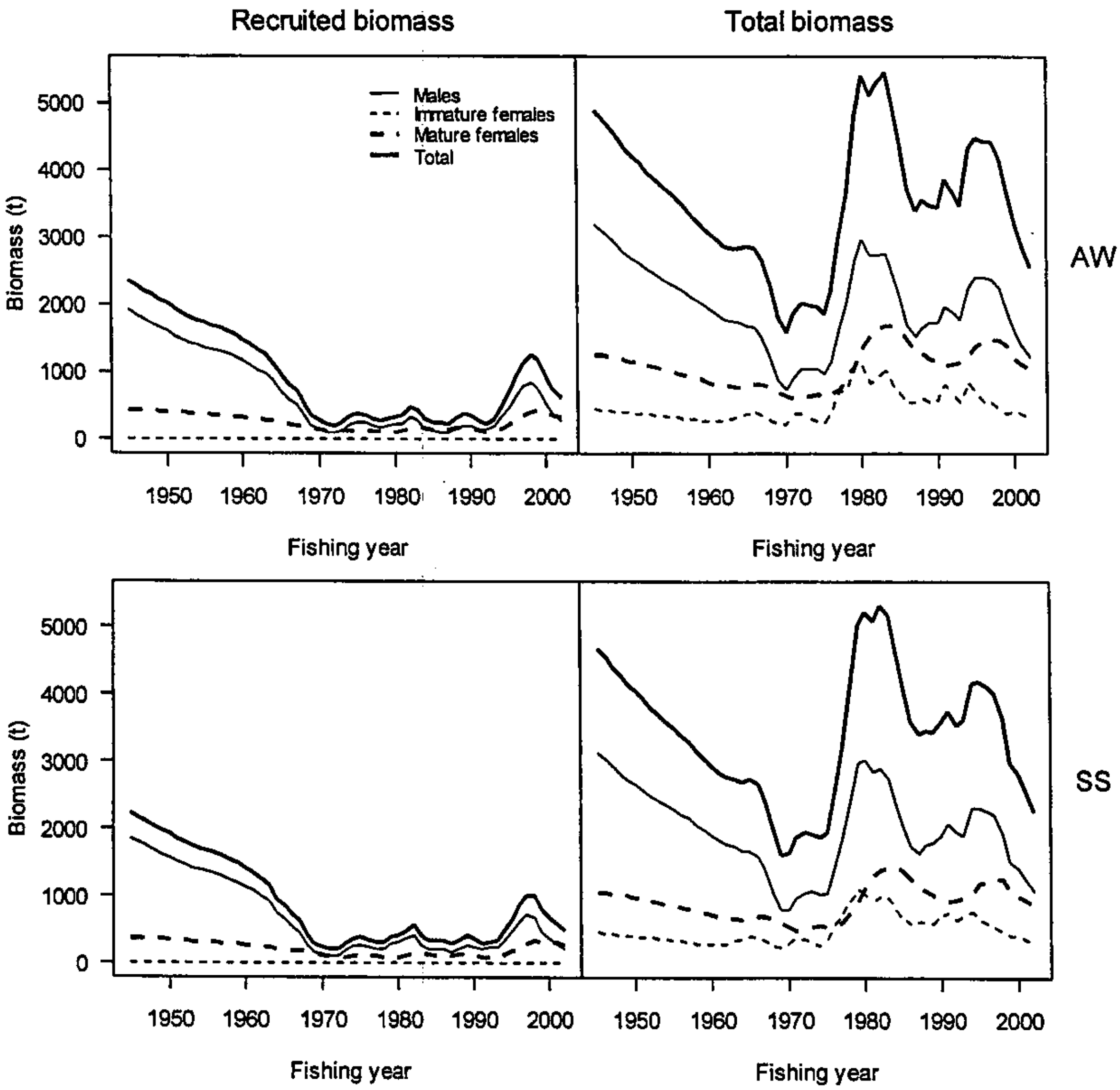
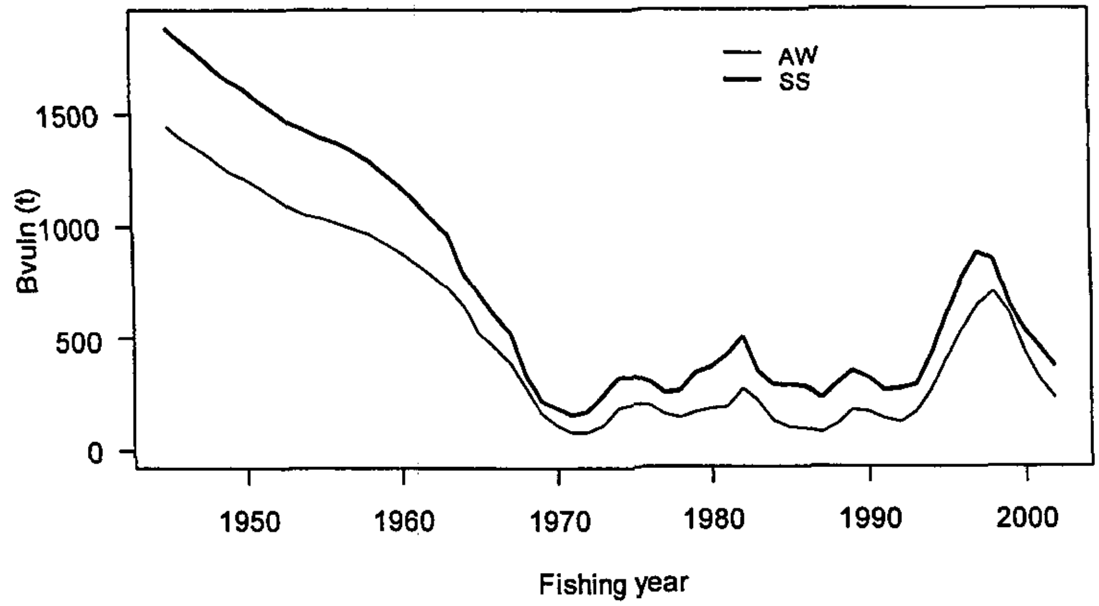


Figure 24: Box plots of residuals from the base case CRA 3 MPD fit to tag-recapture data, plotted by tag type: Hall, plastic dart tag from HallPrint; WRL, SPYR, sphyrion tag, western rock lobster tag.



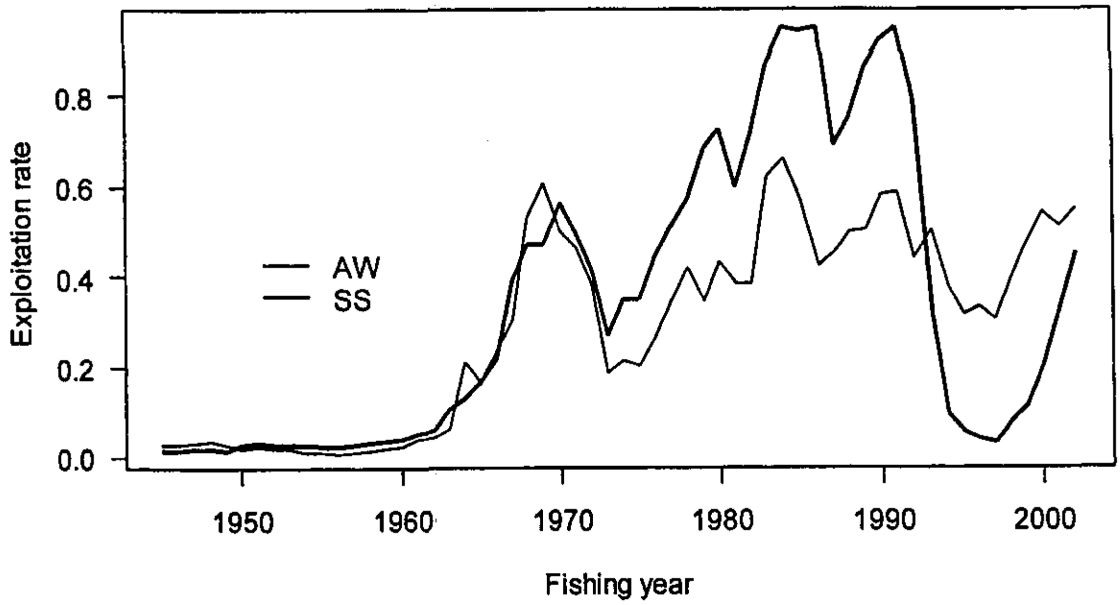
001 : Recruited biomass and total biomass

Figure 25: Recruited (left panels) and total biomass (right panels) from the base case CRA 3 MPD fit, plotted by sex and season.



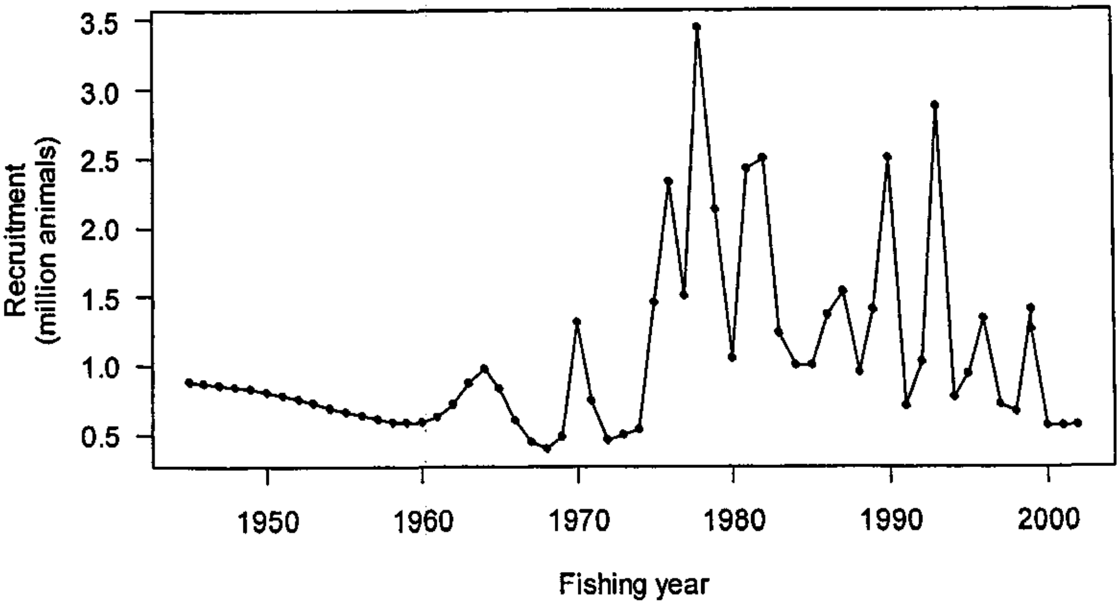
001 : Vulnerable Biomass

Figure 26: Predicted vulnerable biomass from the CRA 3 base case MPD fit, plotted by season.



001 : Erate plot

Figure 27: SL exploitation rate trajectories from the CRA 3 base case MPD fit plotted by season.



001 : Recruitment plot

Figure 28: Recruitment trajectory (millions) from the CRA 3 base case MPD fit.

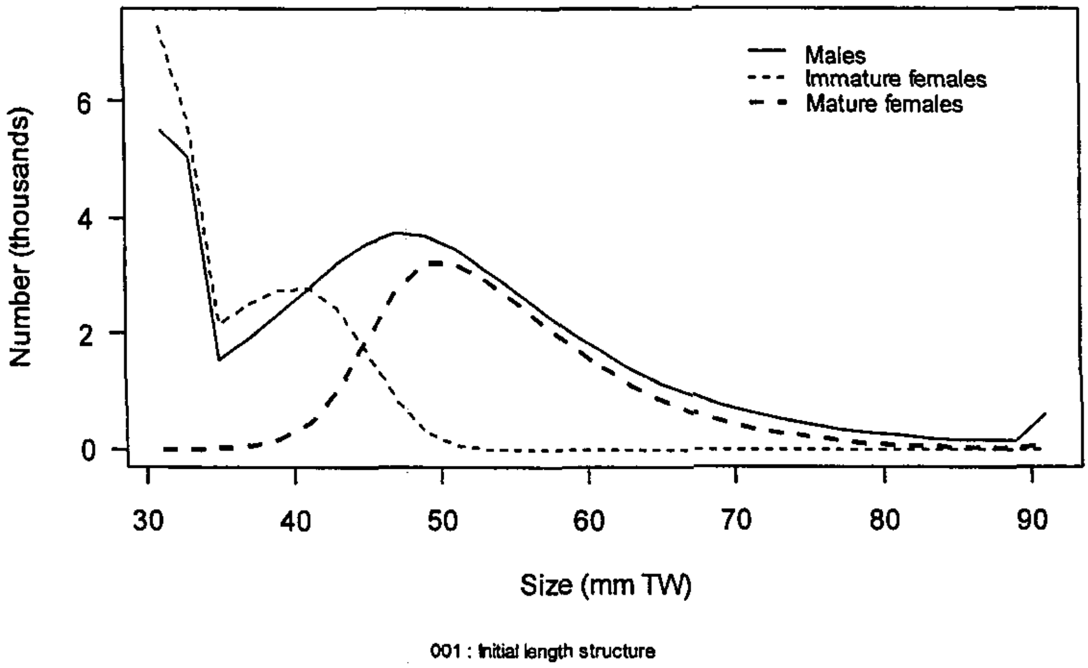


Figure 29: Initial length structure from the CRA base case MPD fit for each sex category.

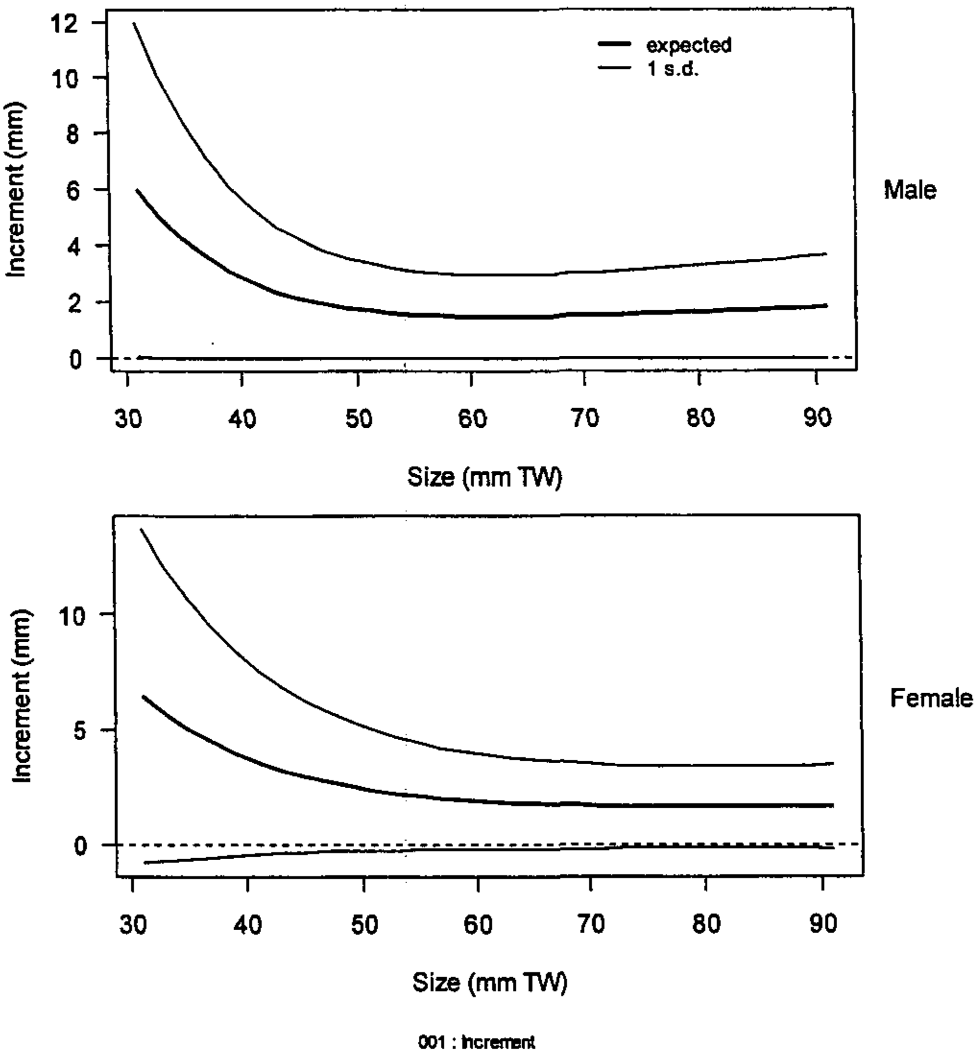
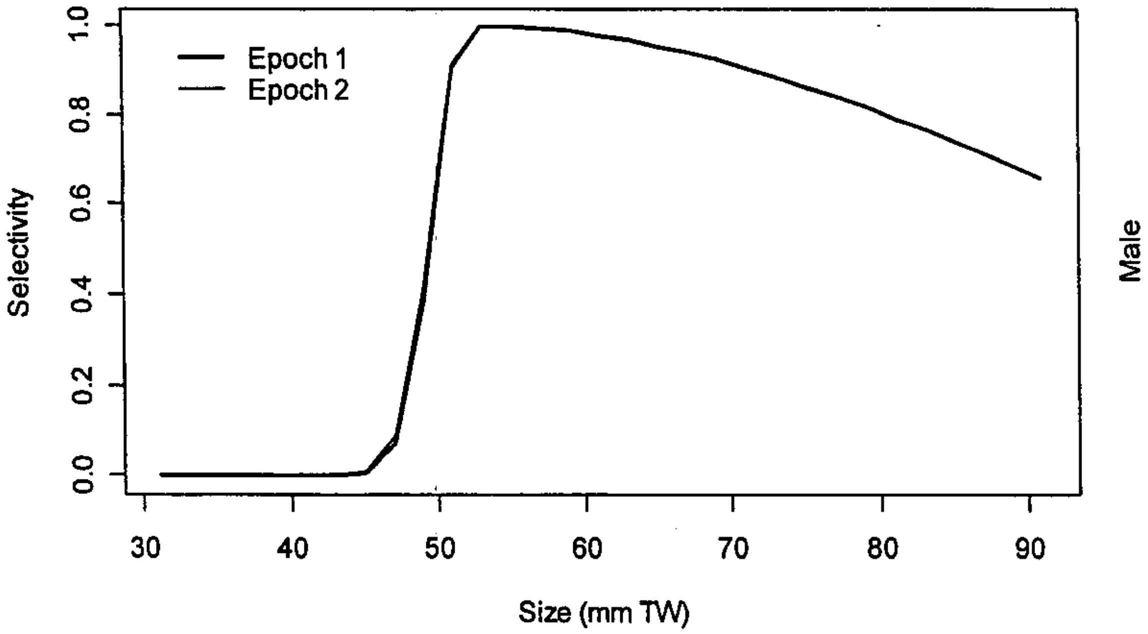
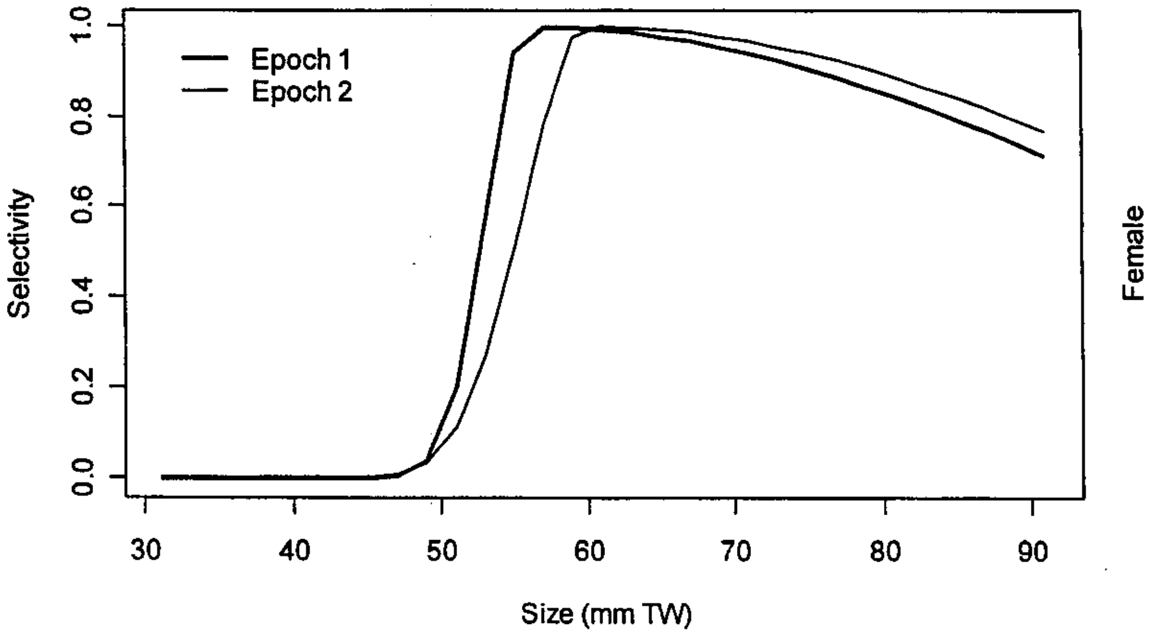


Figure 30: Annual growth increments (thick line) from the CRA 3 base case MPD fit plotted against initial size by sex, shown with one standard deviation around the increment (thin line).



001 : Selectivity curve by Epoch by sex

Figure 31: Selectivity for males in each epoch from the CRA 3 base case MPD fit: epoch 1 extends from 1945 to 1992, epoch 2 from 1993 onwards.



001 : Selectivity curve by Epoch by sex

Figure 32: Selectivity for females in each epoch from the CRA 3 base case MPD fit: epoch 1 extends from 1945 to 1992, epoch 2 from 1993 onwards.

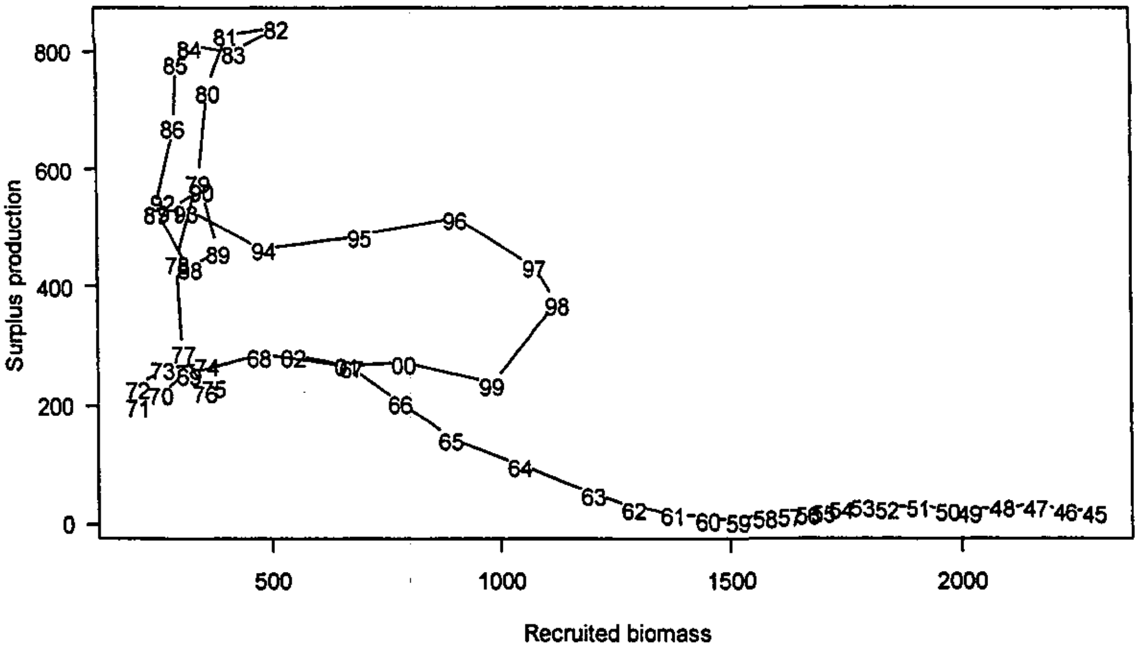


Figure 33: Surplus production from the CRA 3 base case MPD fit plotted against recruited biomass. The labels indicate the last two digits of the fishing year.

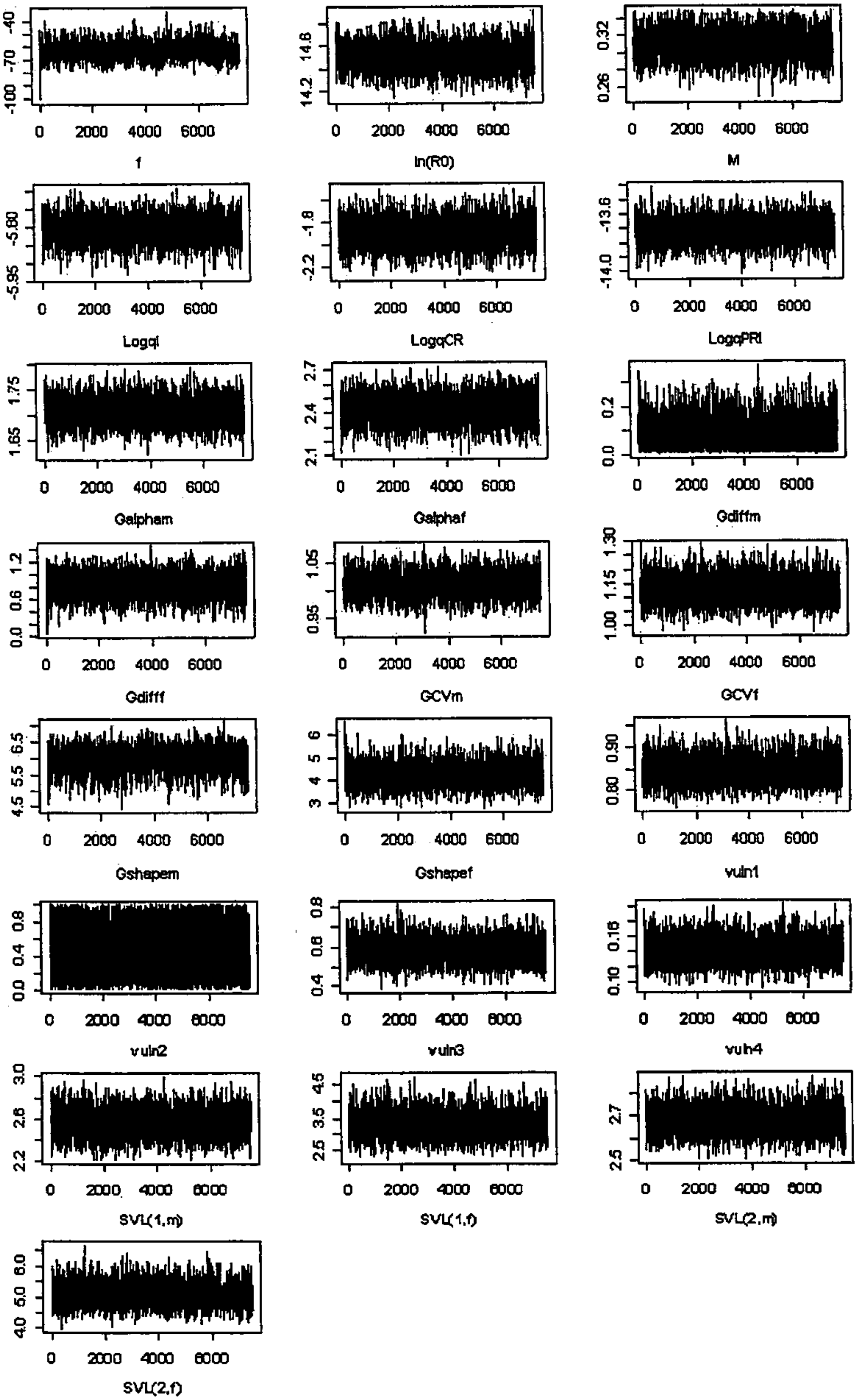


Figure 34: Traces from the CRA 3 base case McMC simulations.

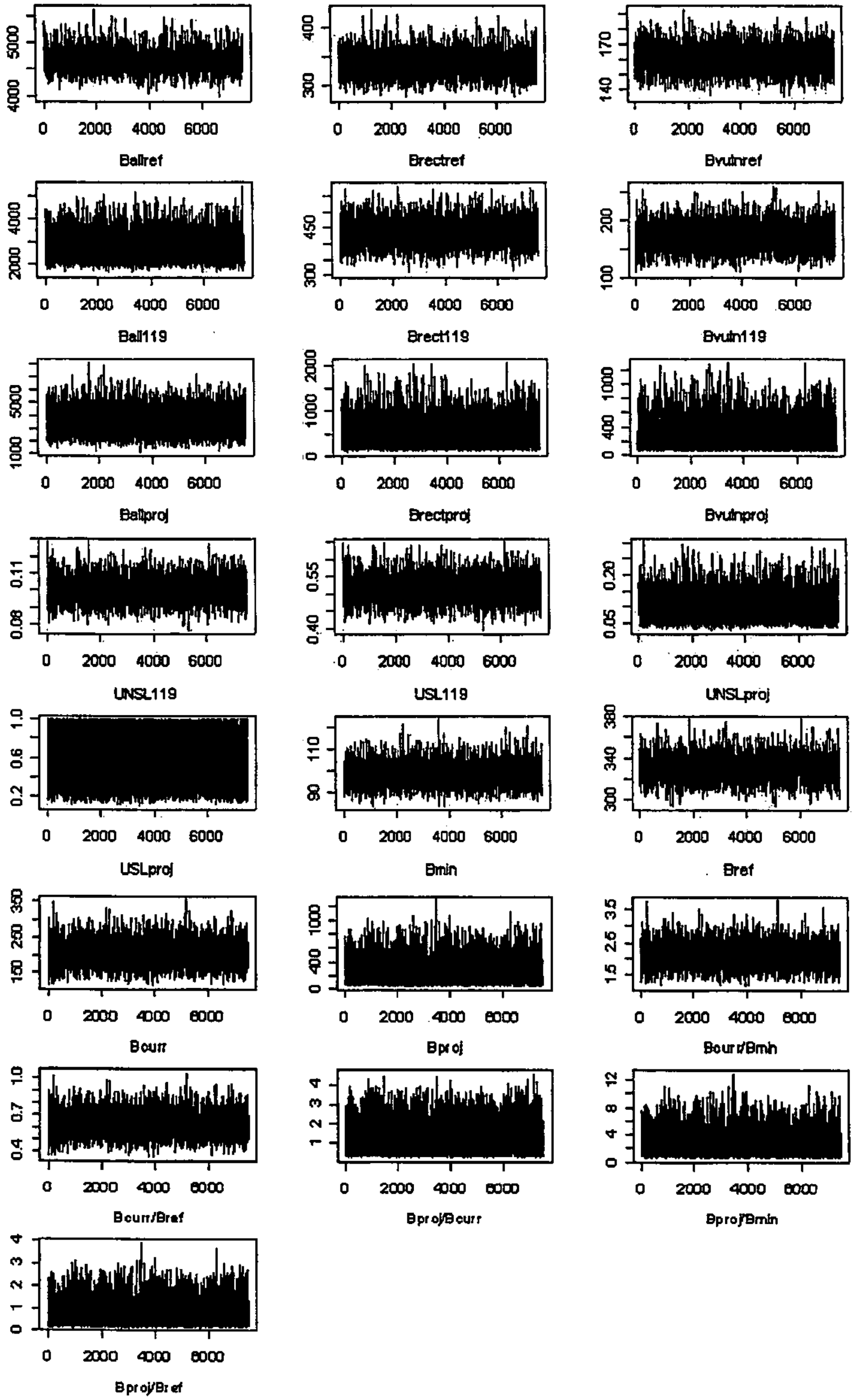


Figure 34: continued.

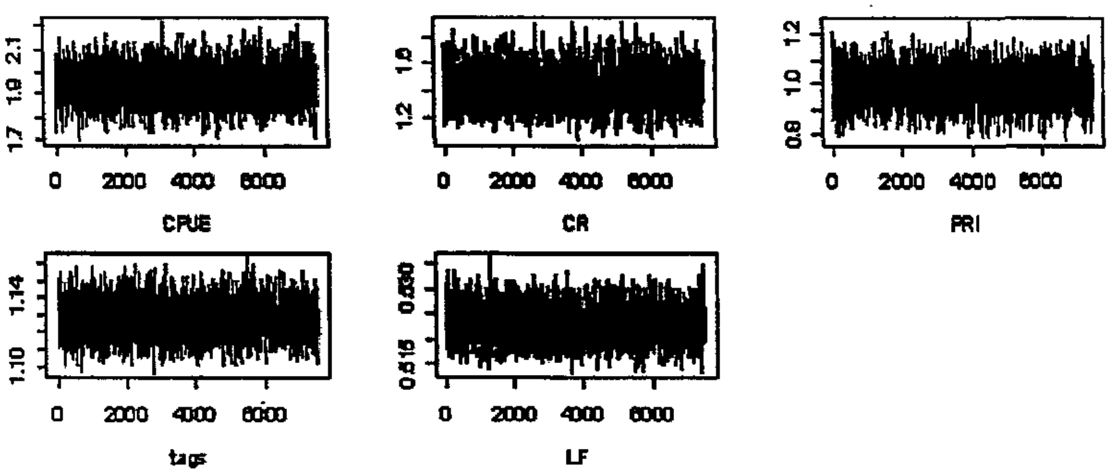


Figure 34: continued.

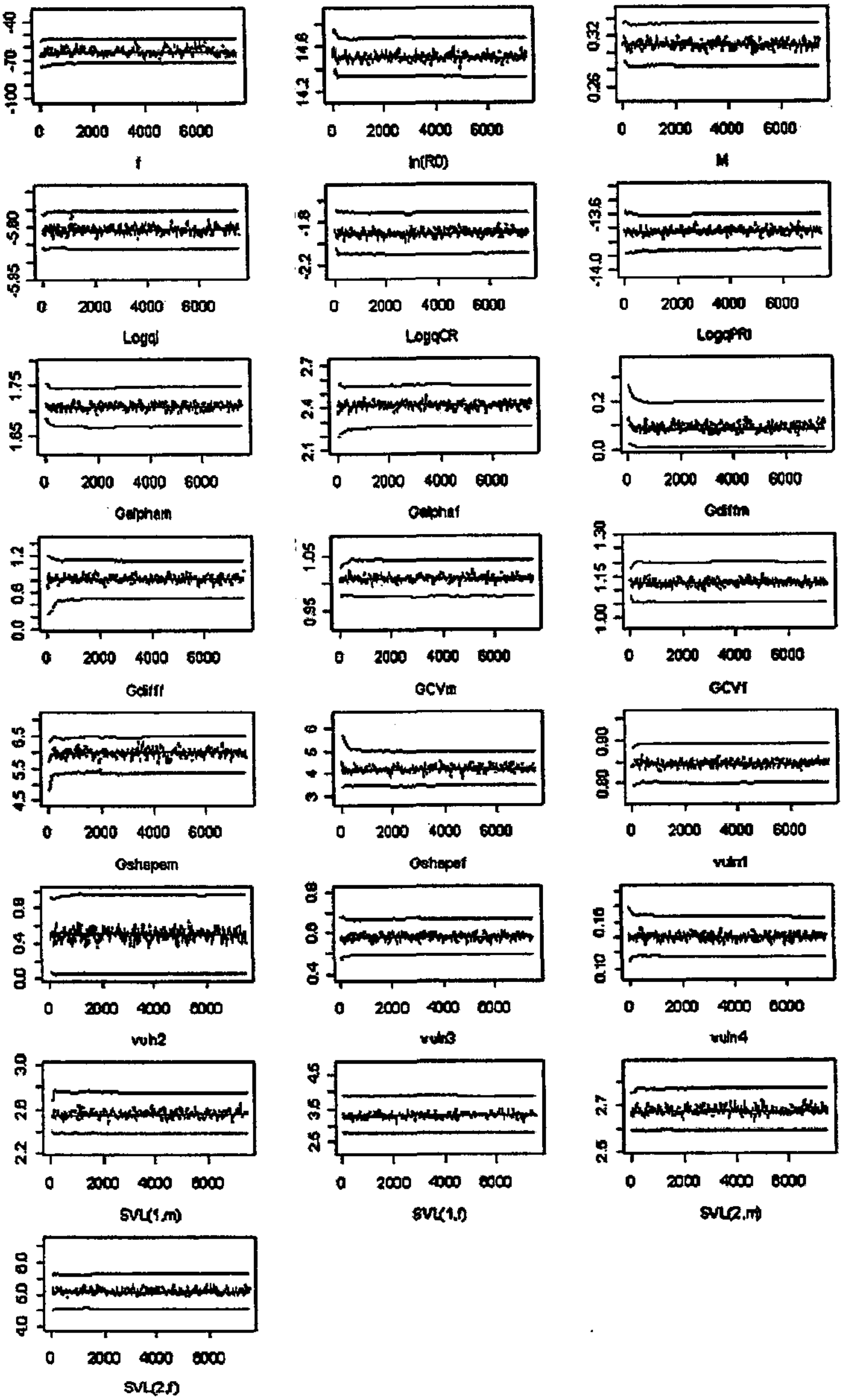


Figure 35: Running averages of traces from the CRA 3 base case McMC simulations for the CRA 3 assessment.

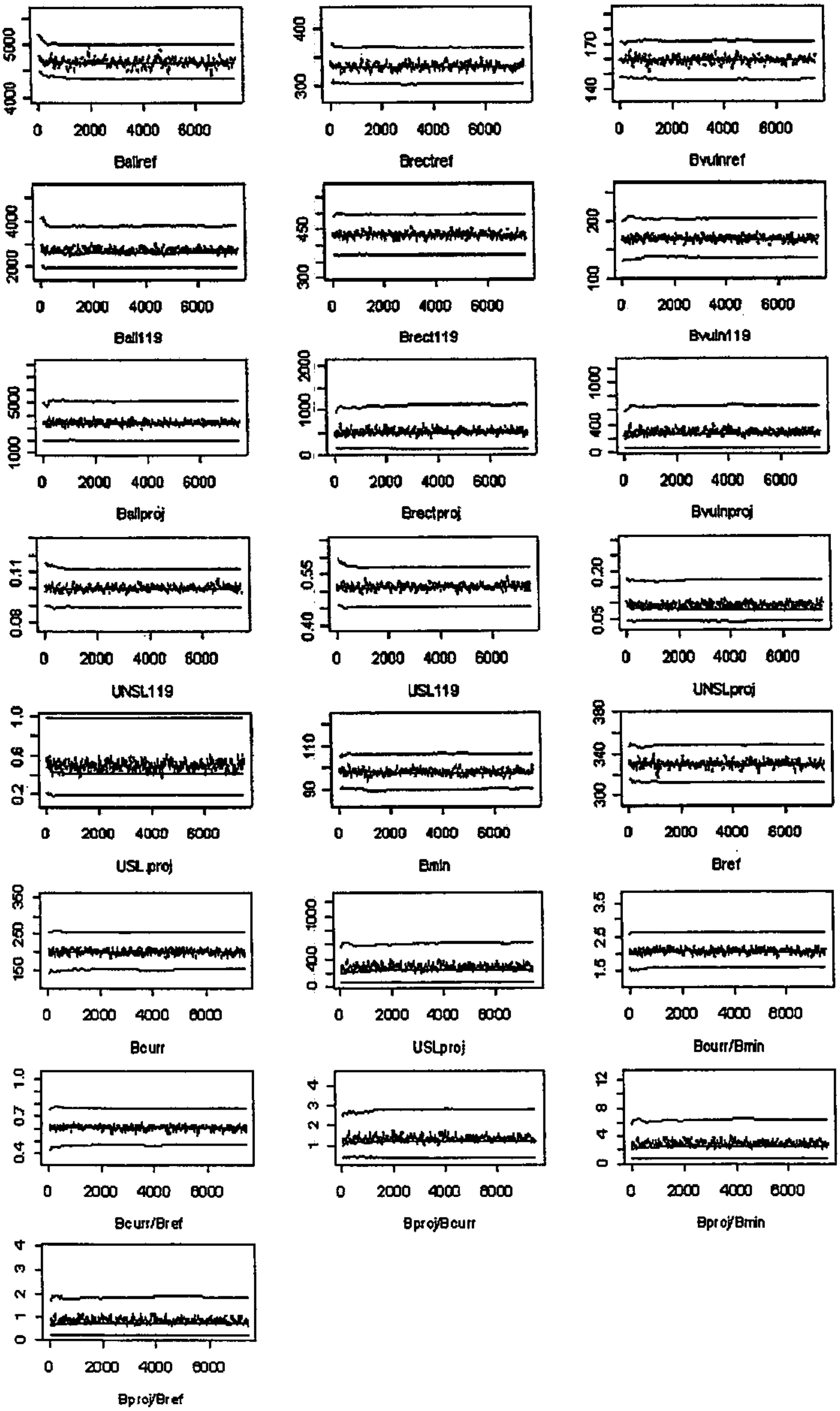
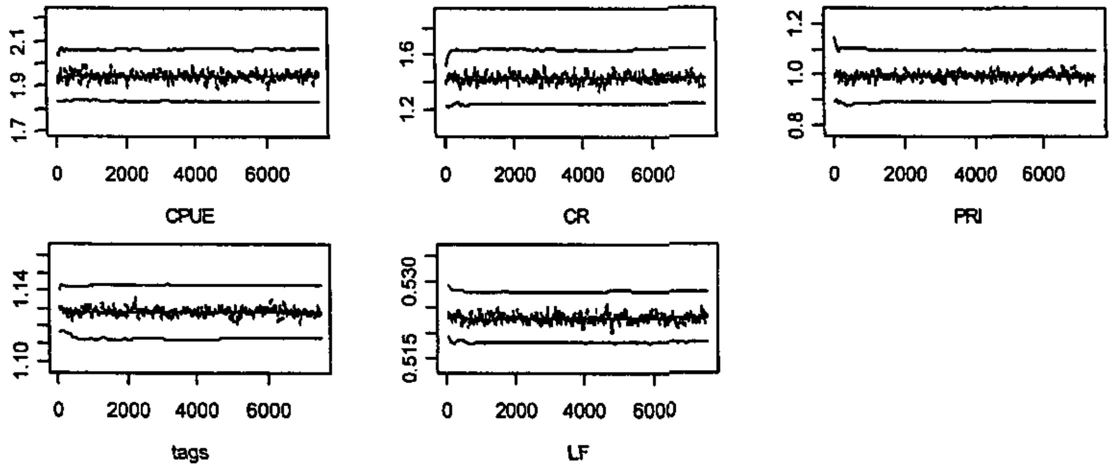


Figure 35: continued.



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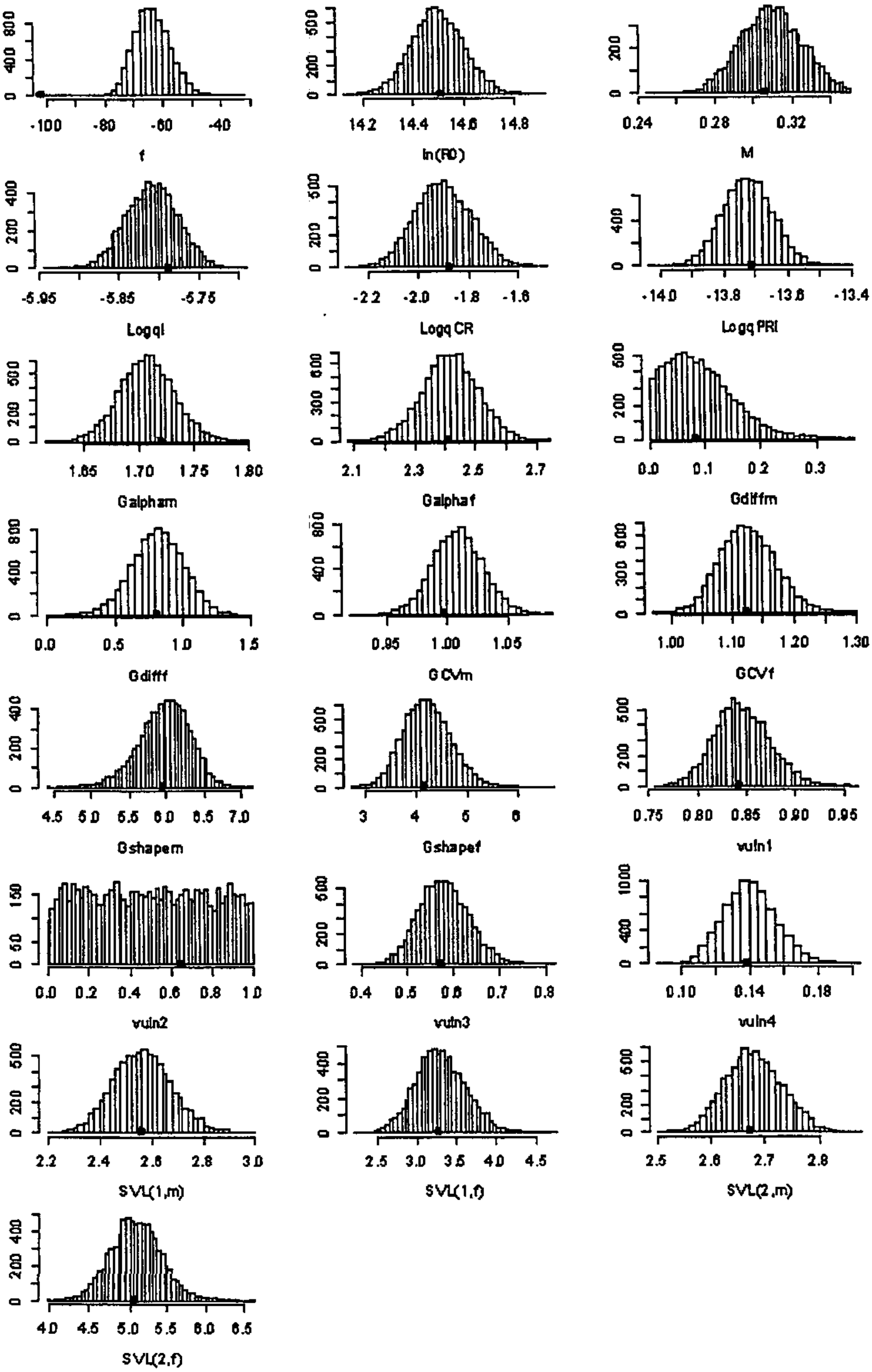
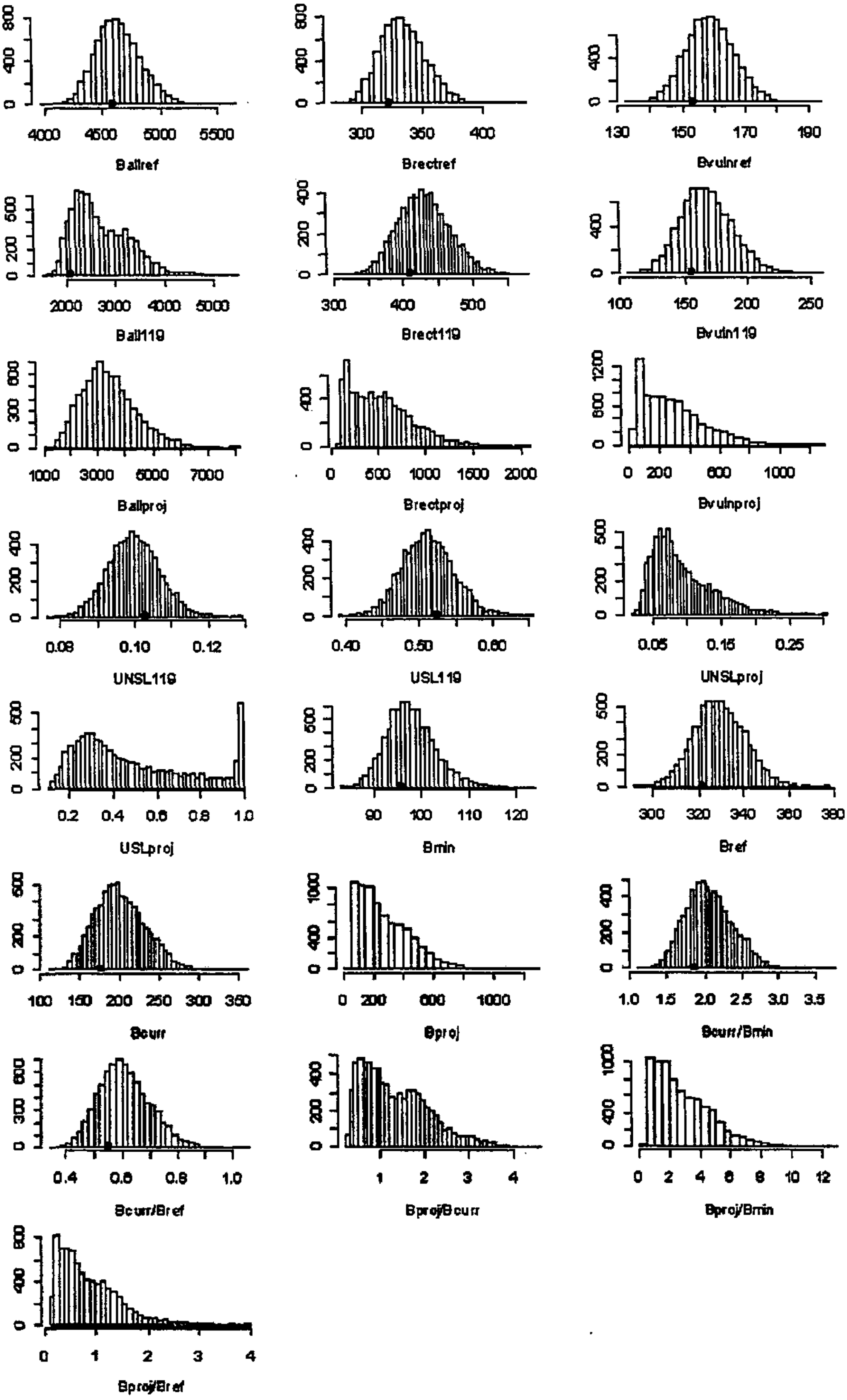


Figure 36: Marginal posterior distributions of parameters and performance indicators from the CRA 3 base case McMC simulations. The MPD estimate for each parameter or performance indicator is indicated by a dot on the x-axis.



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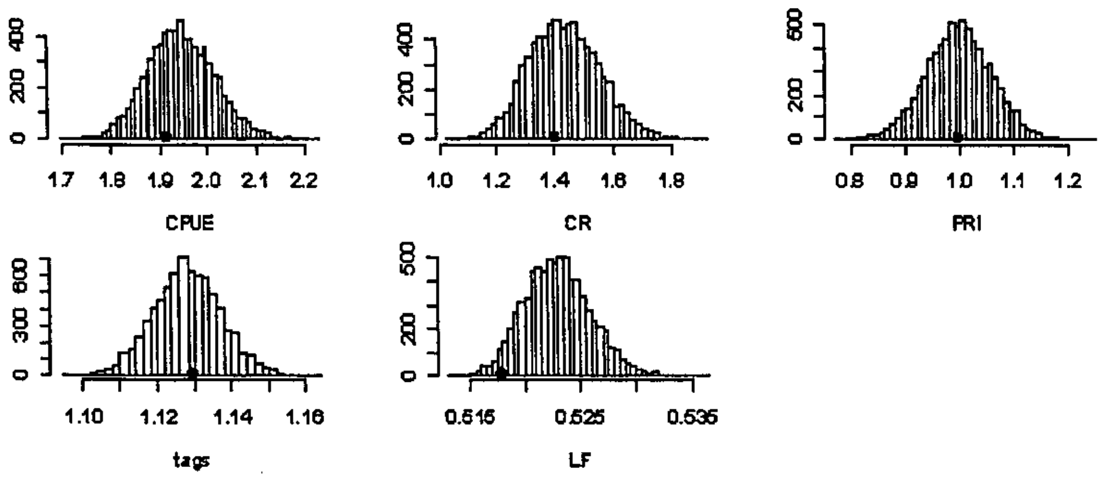

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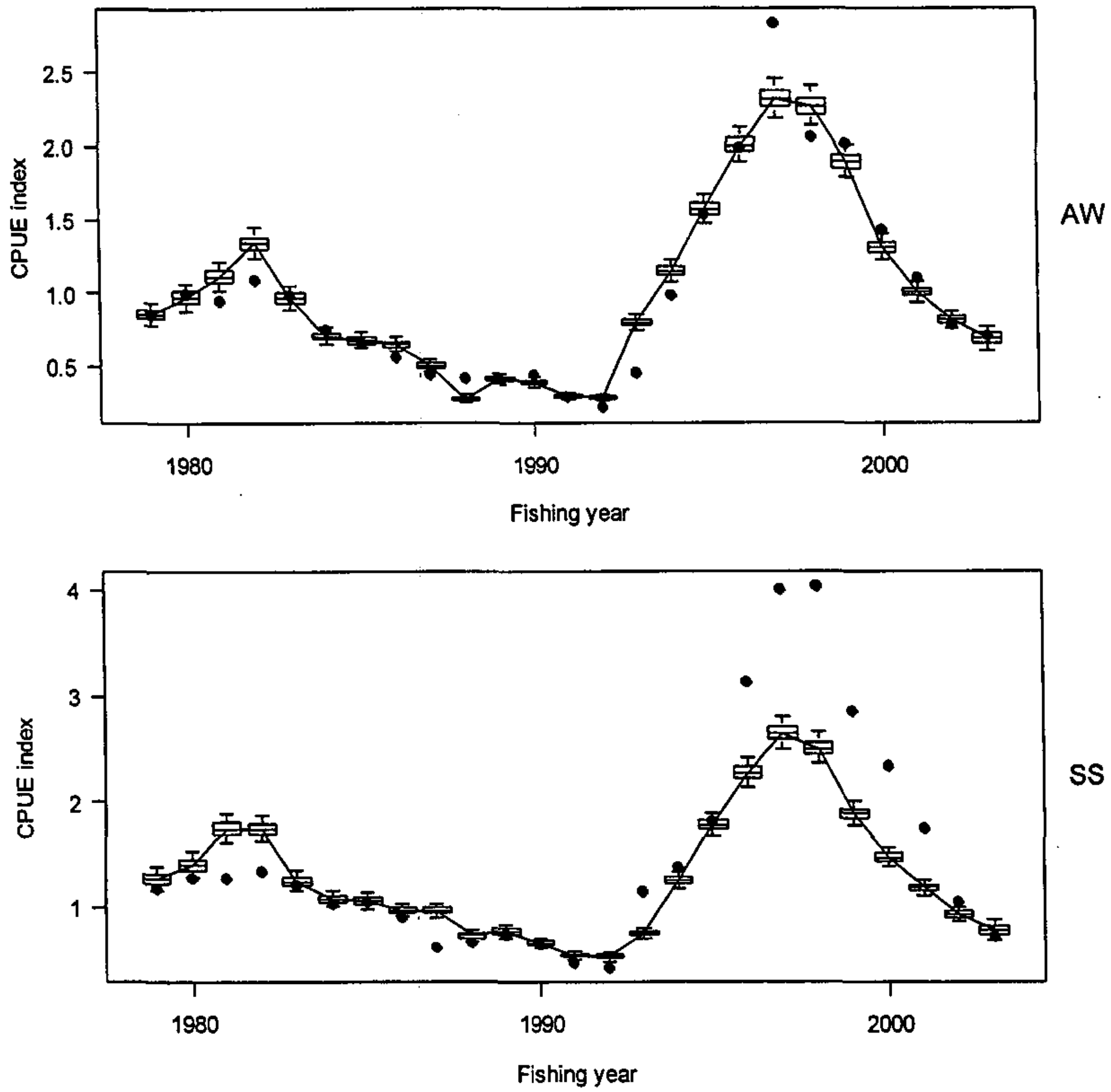


Figure 37: The posterior distributions of the fits to CPUE data from the base case CRA 3 McMC *simulations.*

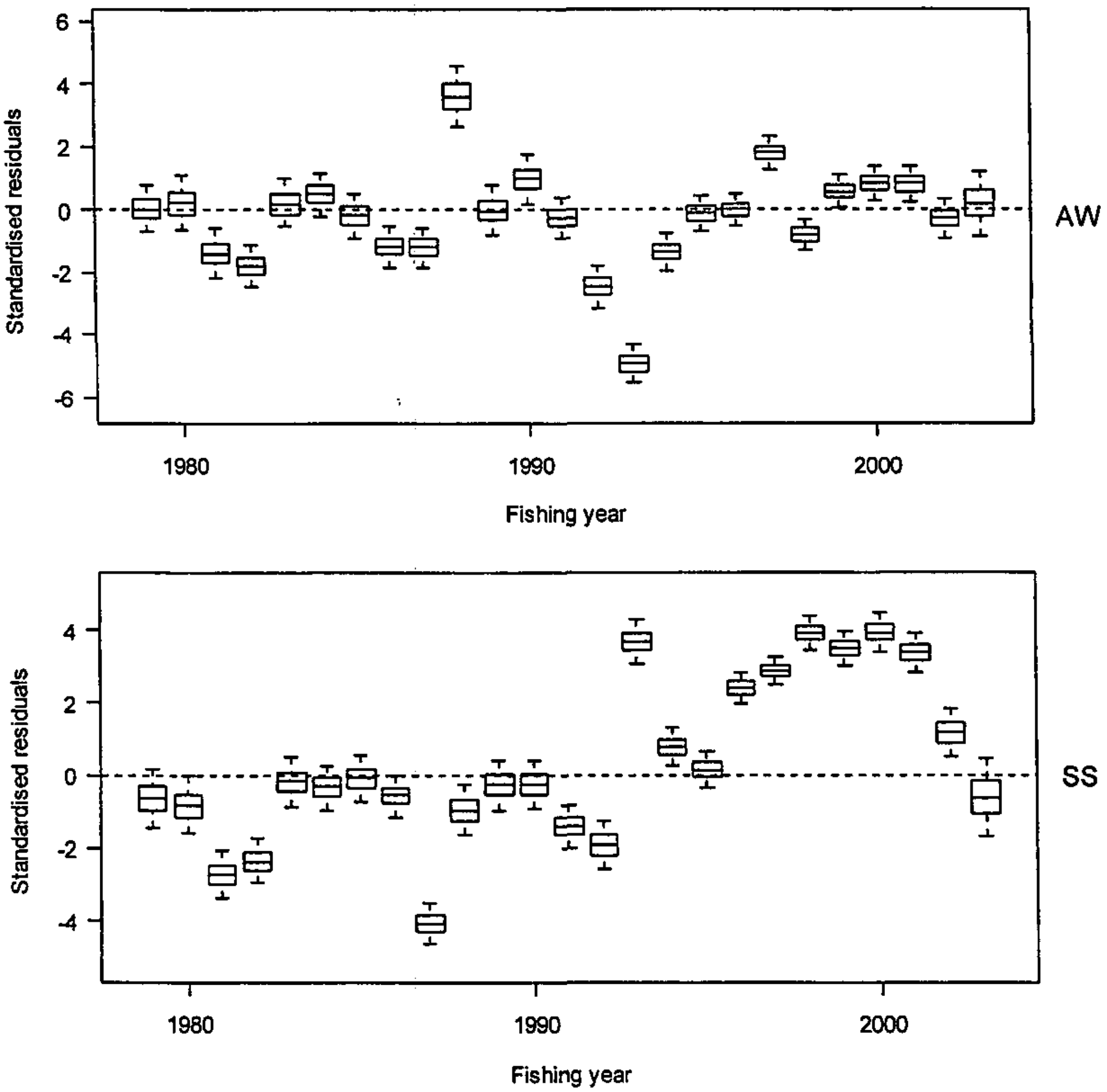
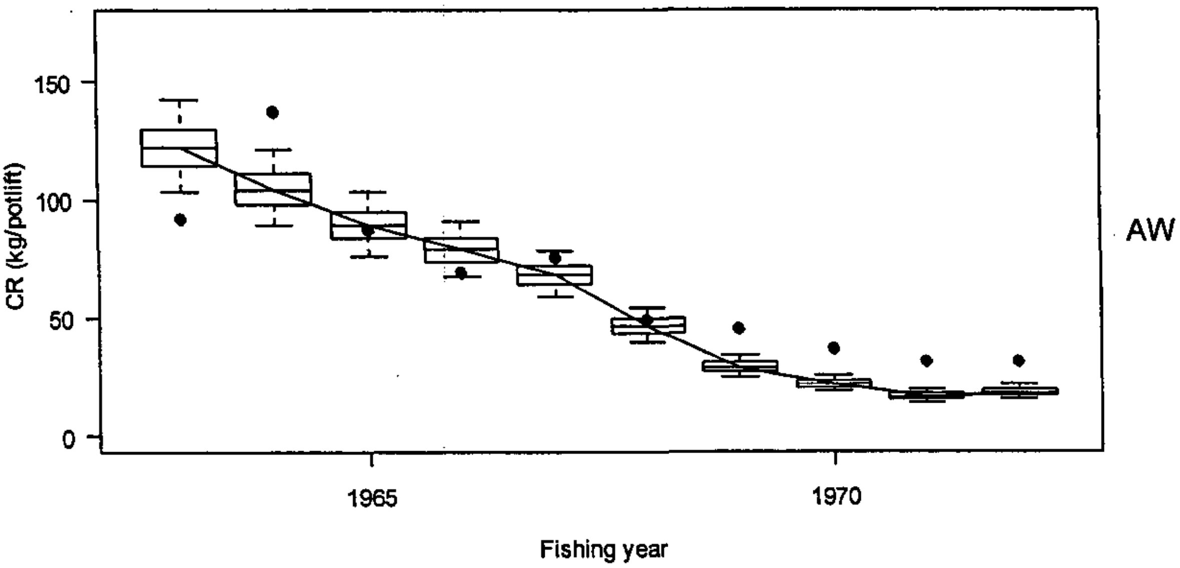


Figure 38: The posterior distributions of the normalised residuals from fit to CPUE in the base case CRA 3 McMC simulations.



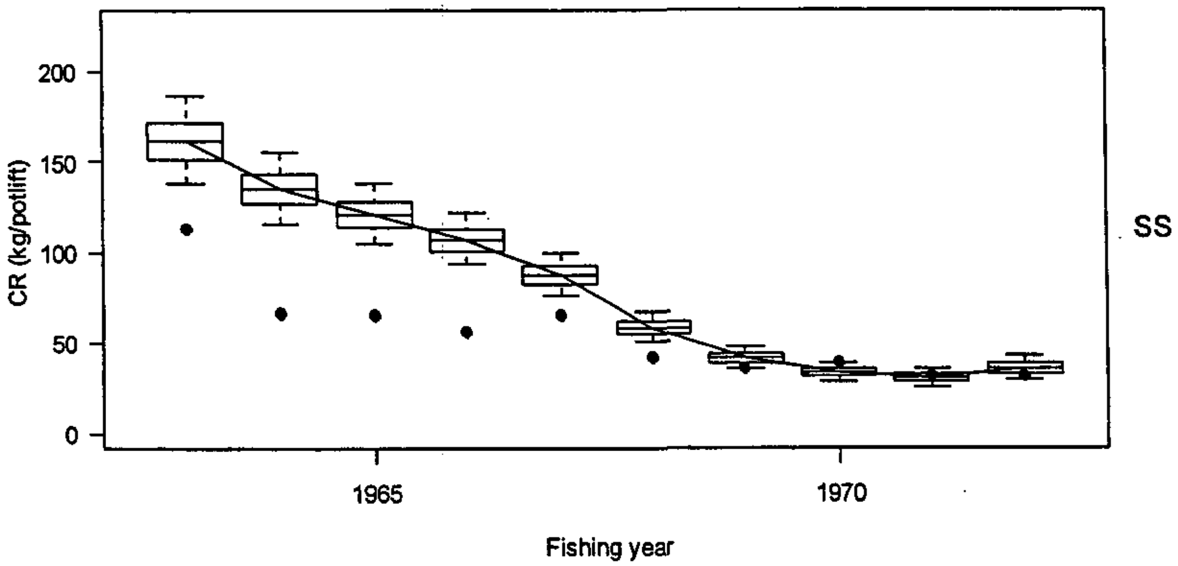


Figure 39: The posterior distributions of the fits to CR data in the base case CRA 3 McMC simulations.

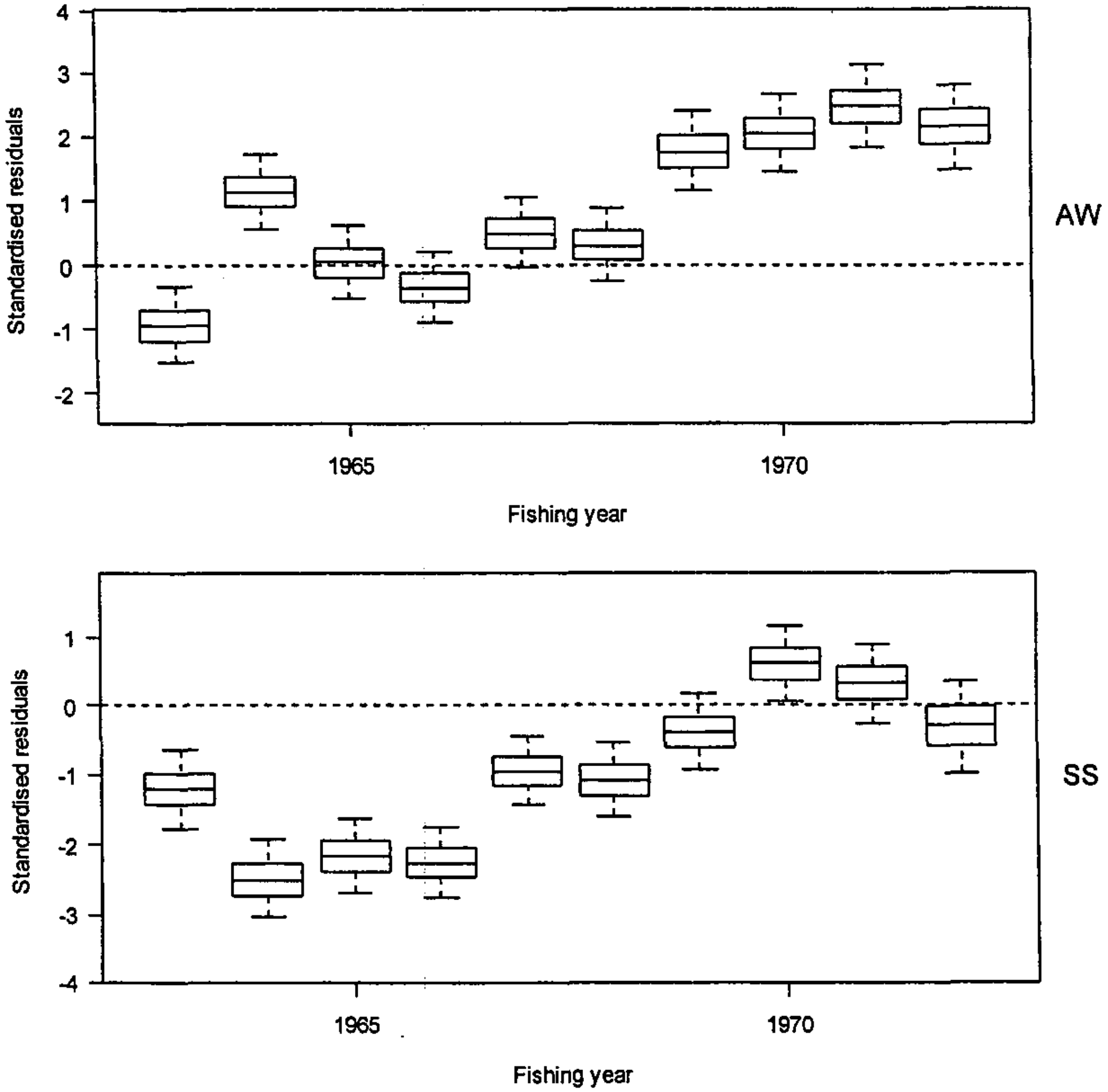


Figure 40: The posterior distributions of the normalised residuals from the CR fit in the base case CRA 3 McMC simulations.

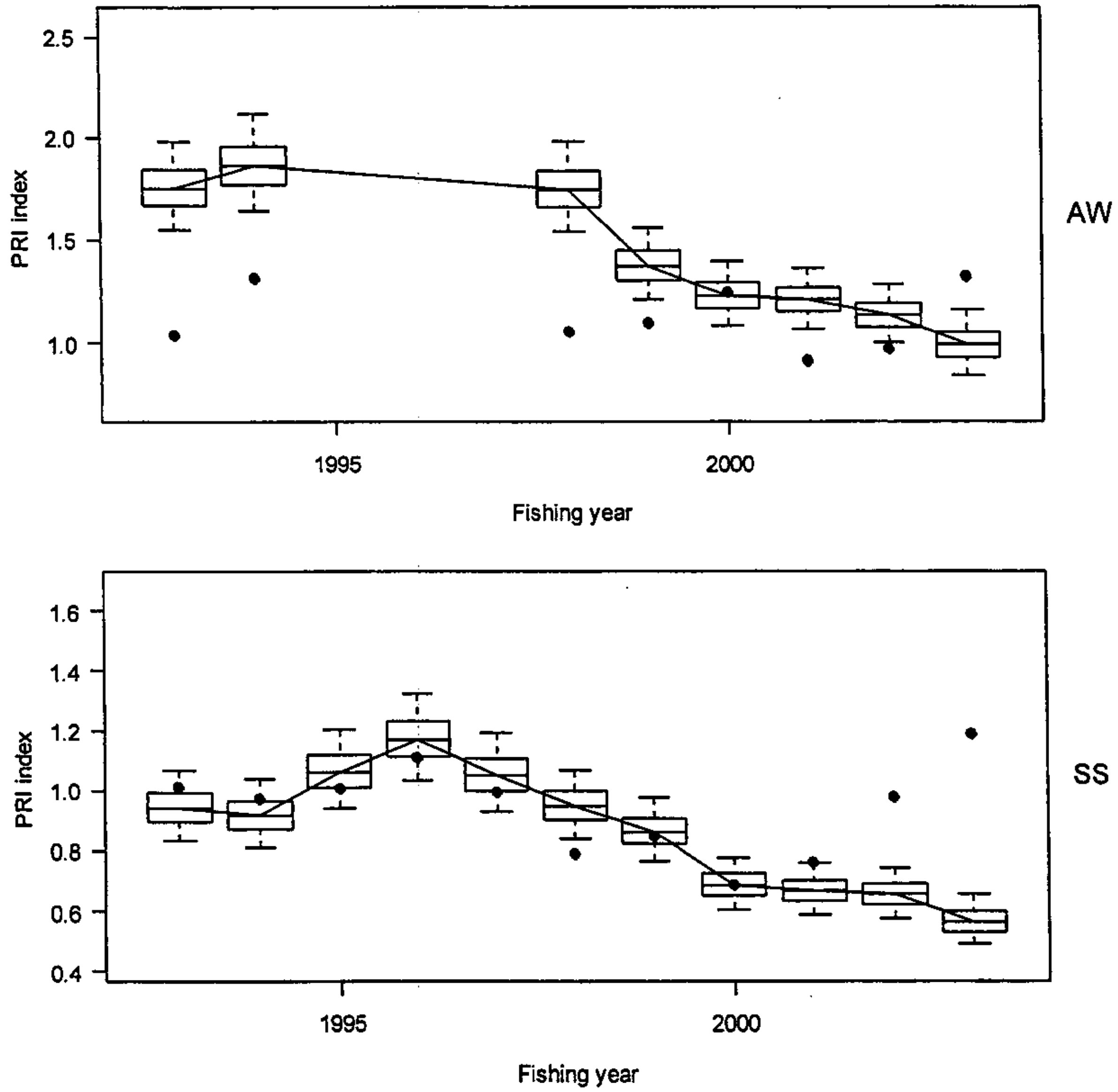


Figure 41: The posterior distributions of the fits to PRI data from the base case CRA 3 McMC simulations.

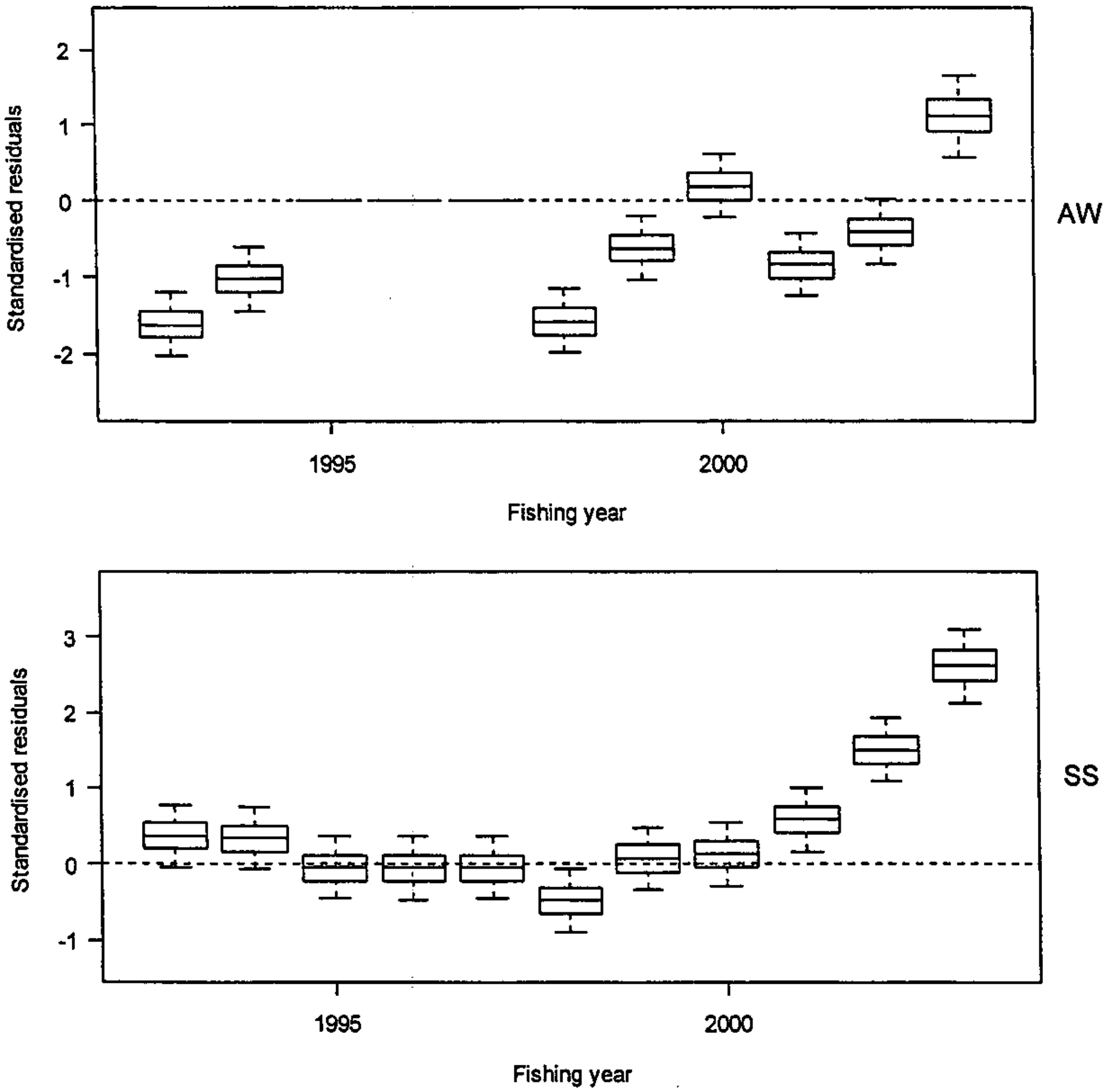


Figure 42: The posterior distributions of the normalised residuals from fir to PRI in the base case CRA 3 McMC simulations.

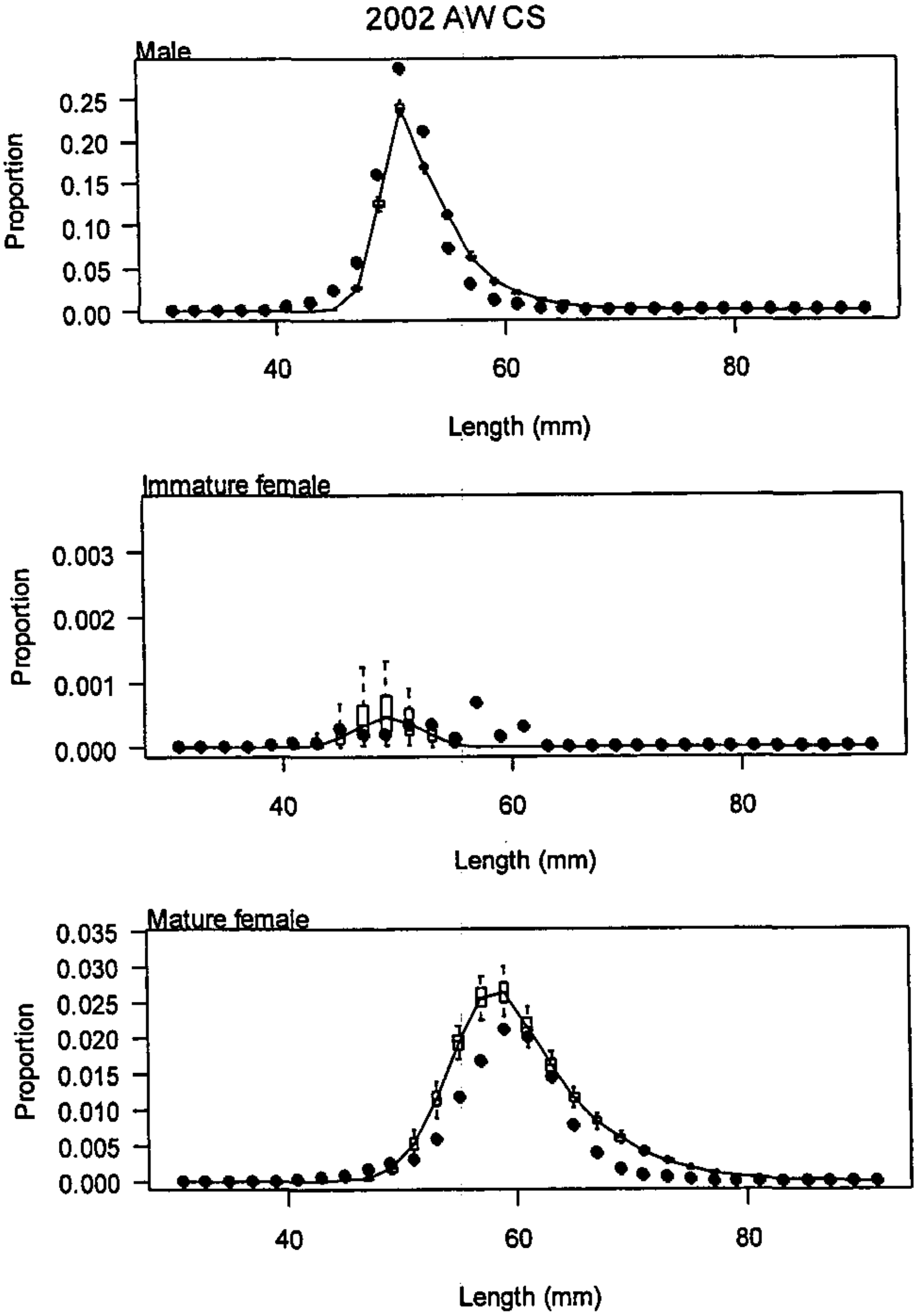


Figure 43: The posterior distributions of the fits to proportions-at-length from 2002 AW catch sampling in the base case CRA 3 McMC simulations.

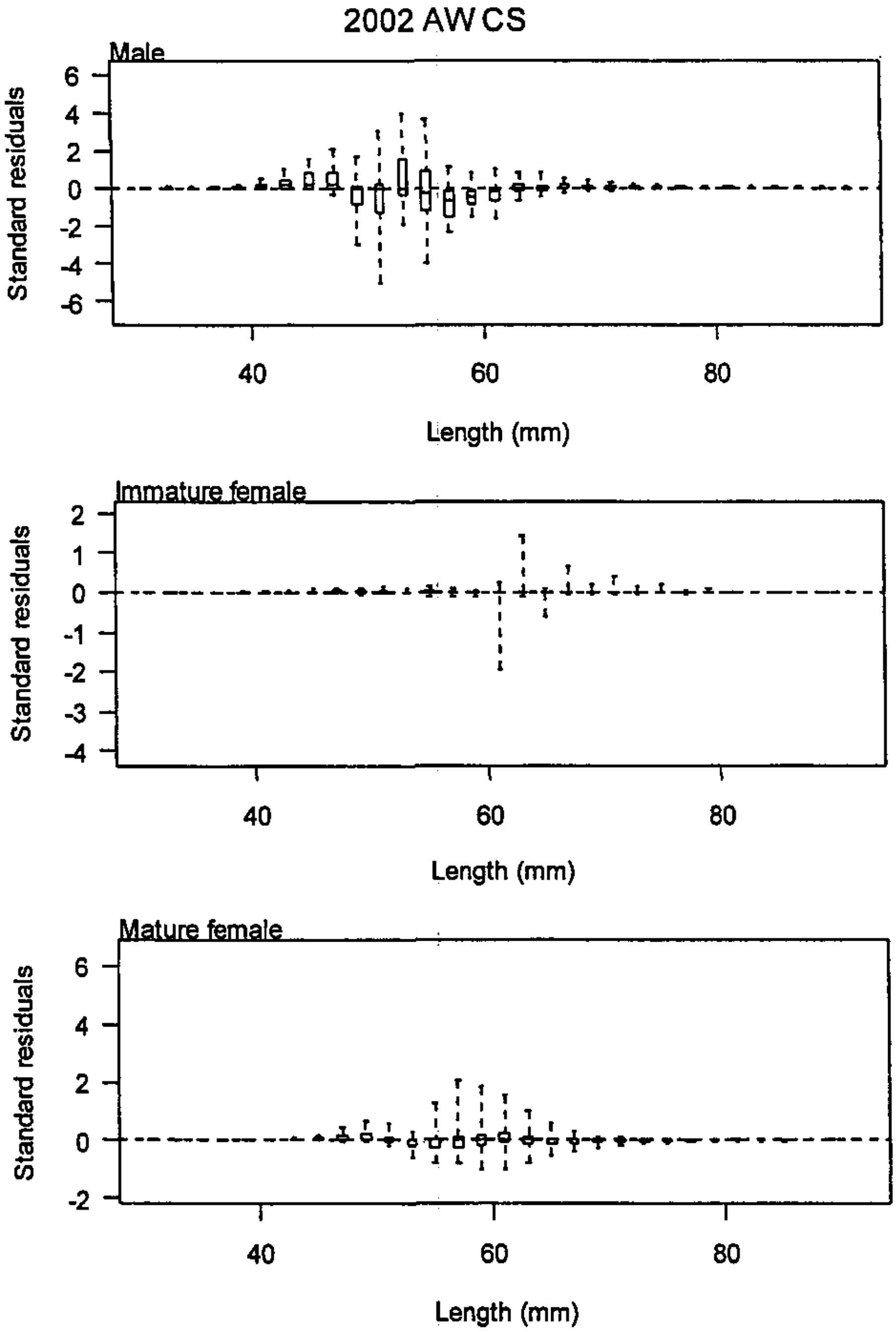


Figure 44: The posterior distributions of the normalised residuals from the fits to proportions-at-length from 2002 AW catch sampling in the base case CRA 3 McMC simulations.

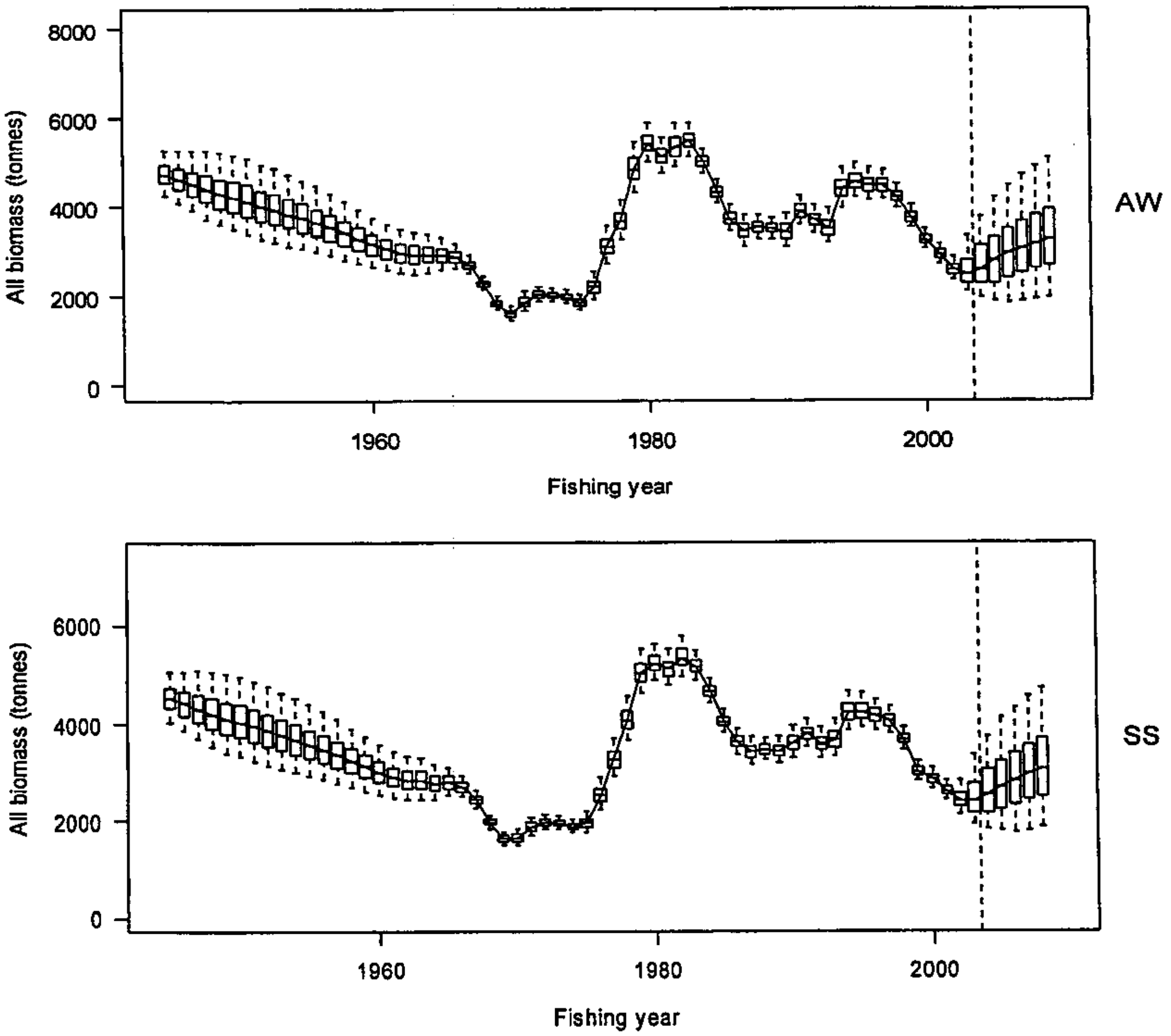


Figure 45: The posterior trajectory of total biomass, by season, from the CRA 3 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

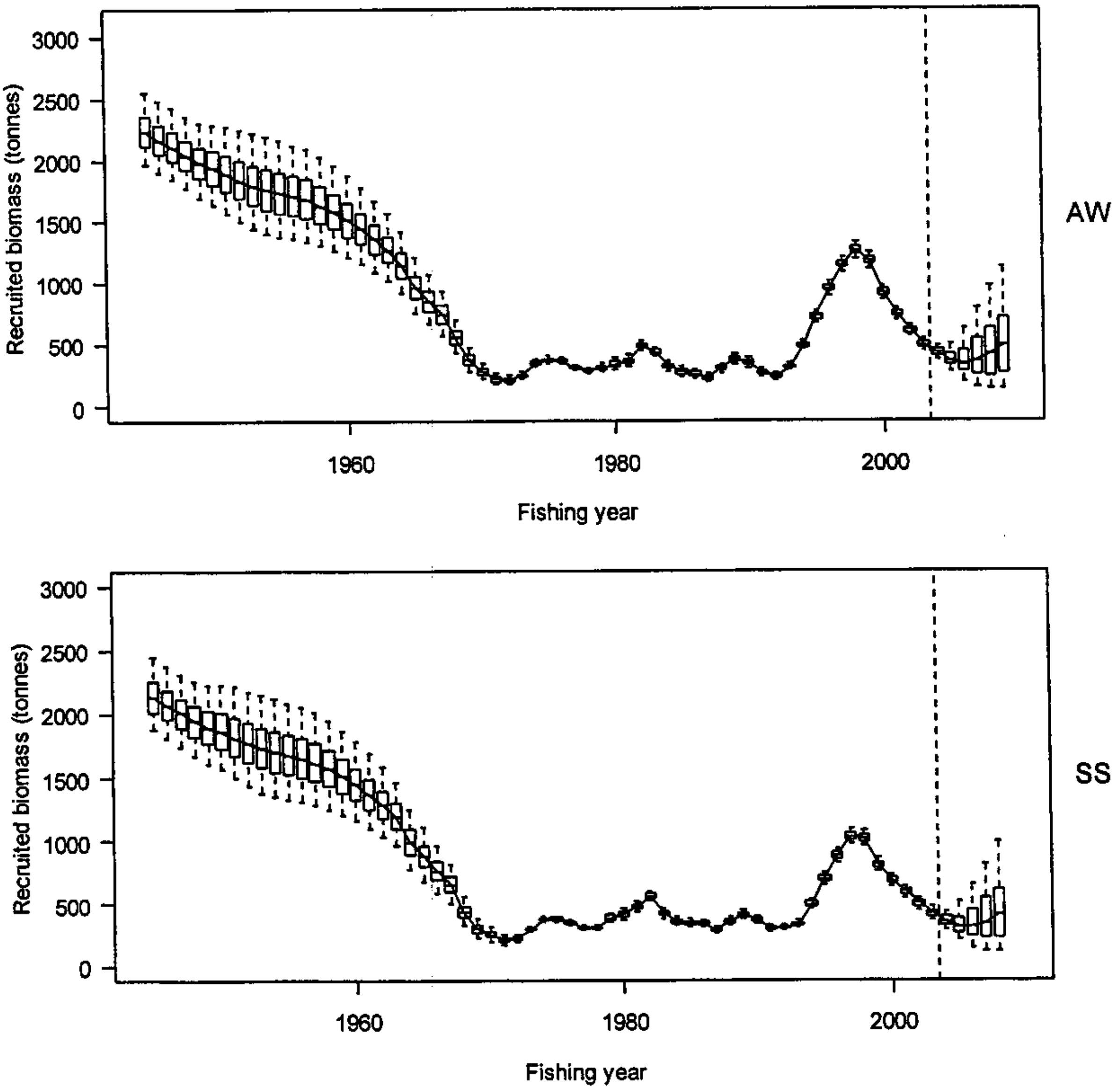


Figure 46: The posterior trajectory of recruited biomass, by season, from the CRA 3 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

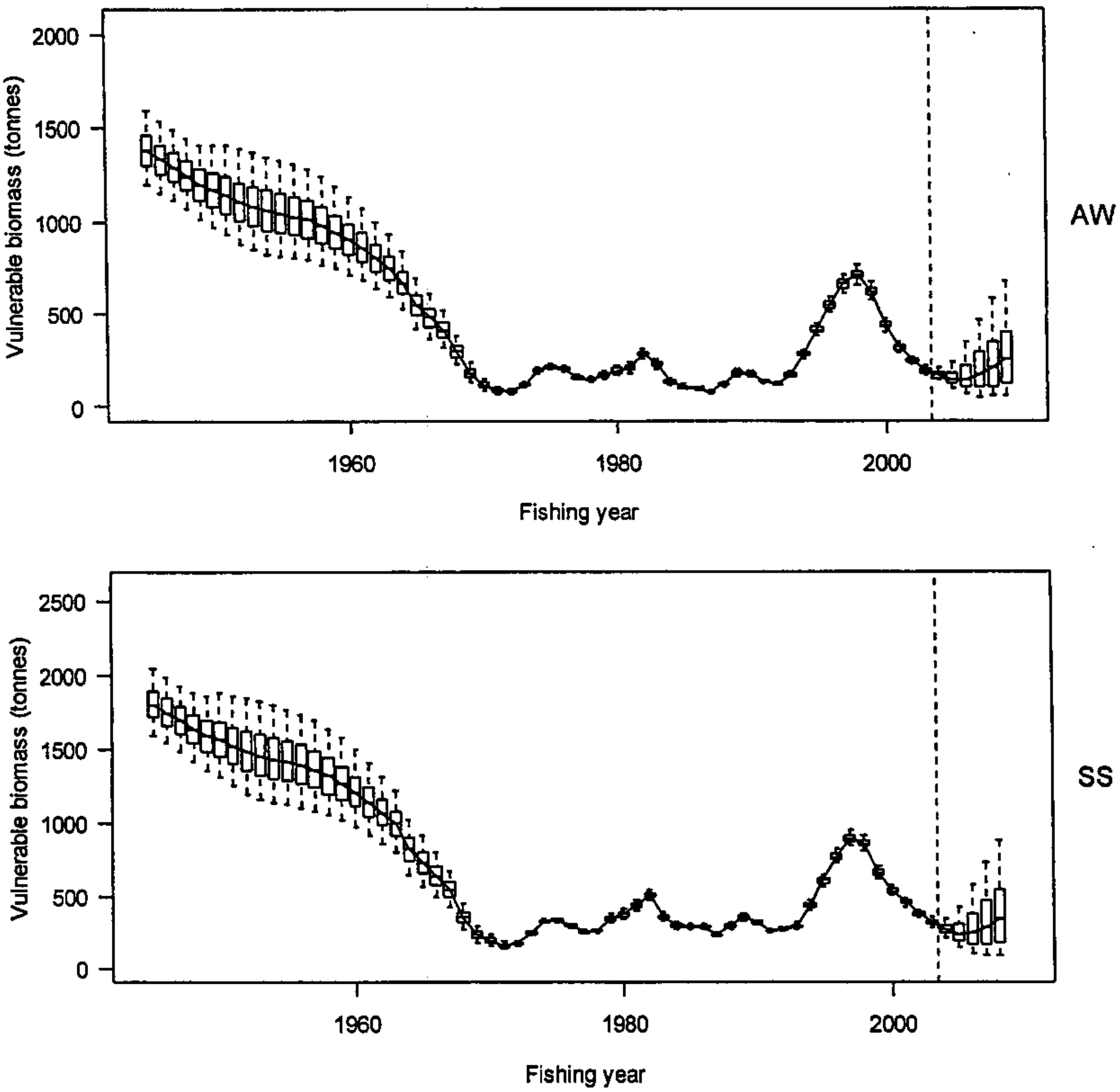


Figure 47: The posterior trajectory of vulnerable biomass, by season, from the CRA 3 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

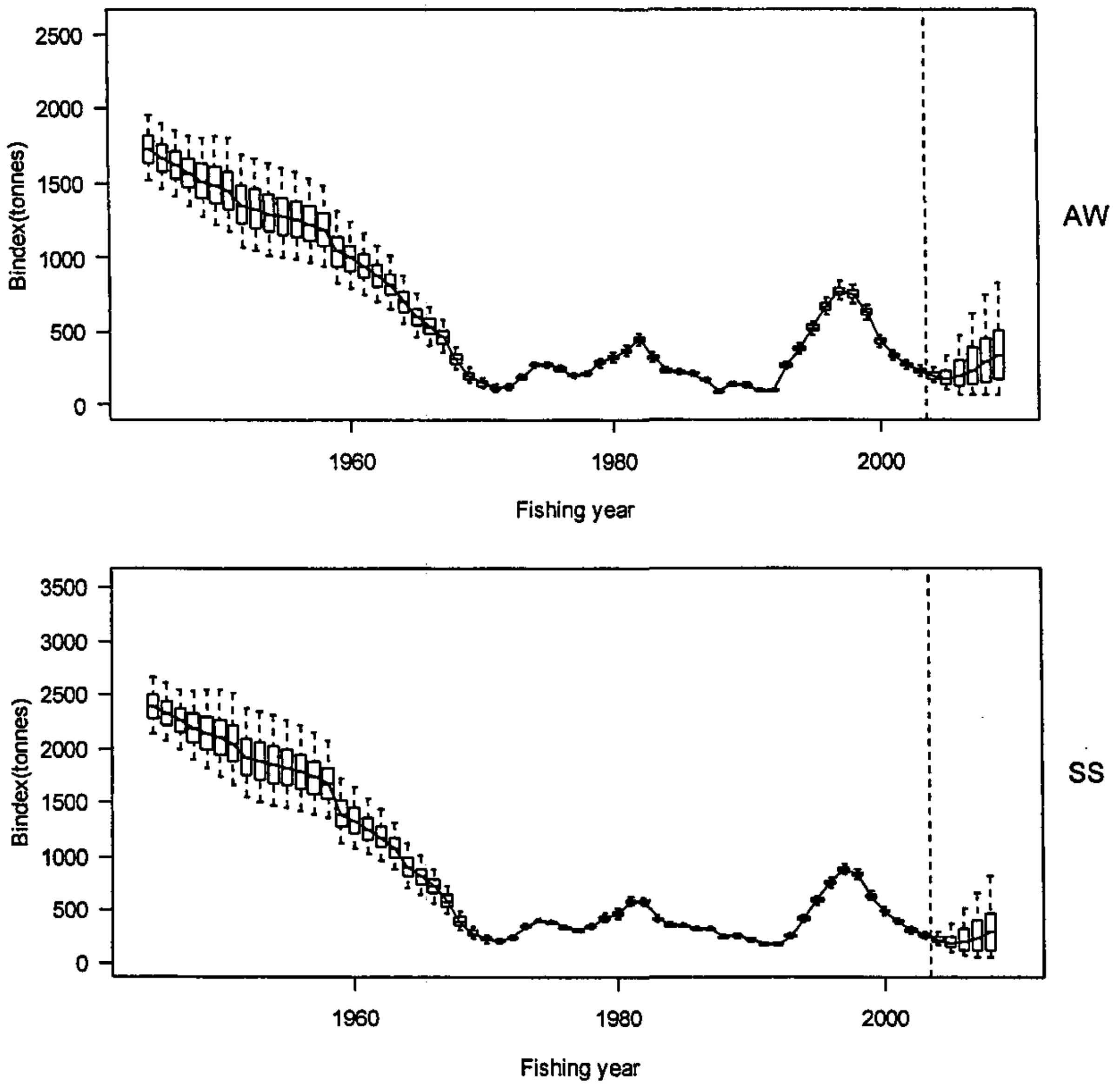


Figure 48: The posterior trajectory of index biomass, by season, from the CRA 3 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

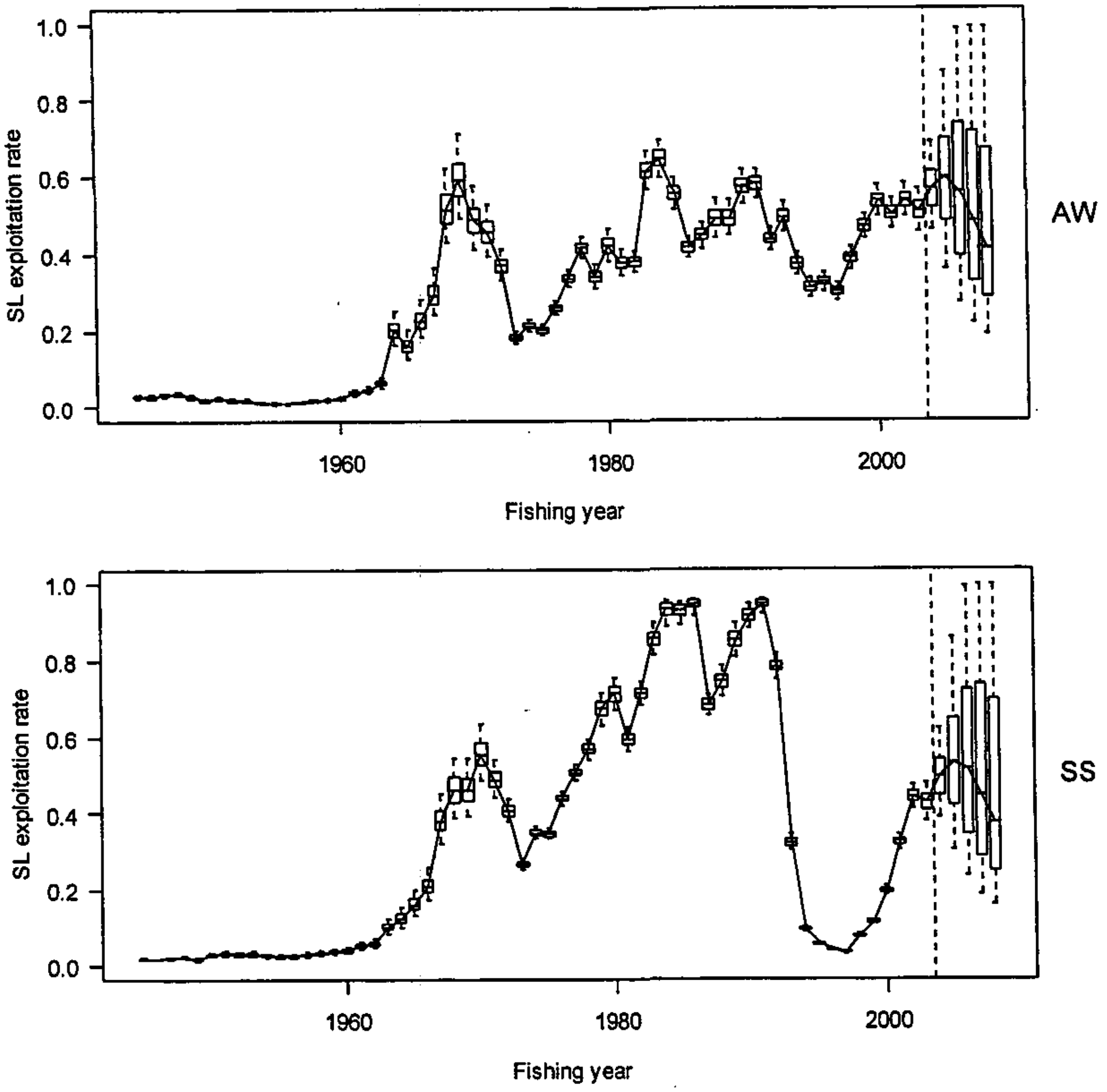


Figure 49: The posterior trajectories of SL exploitation rate, by season, from the CRA 3 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

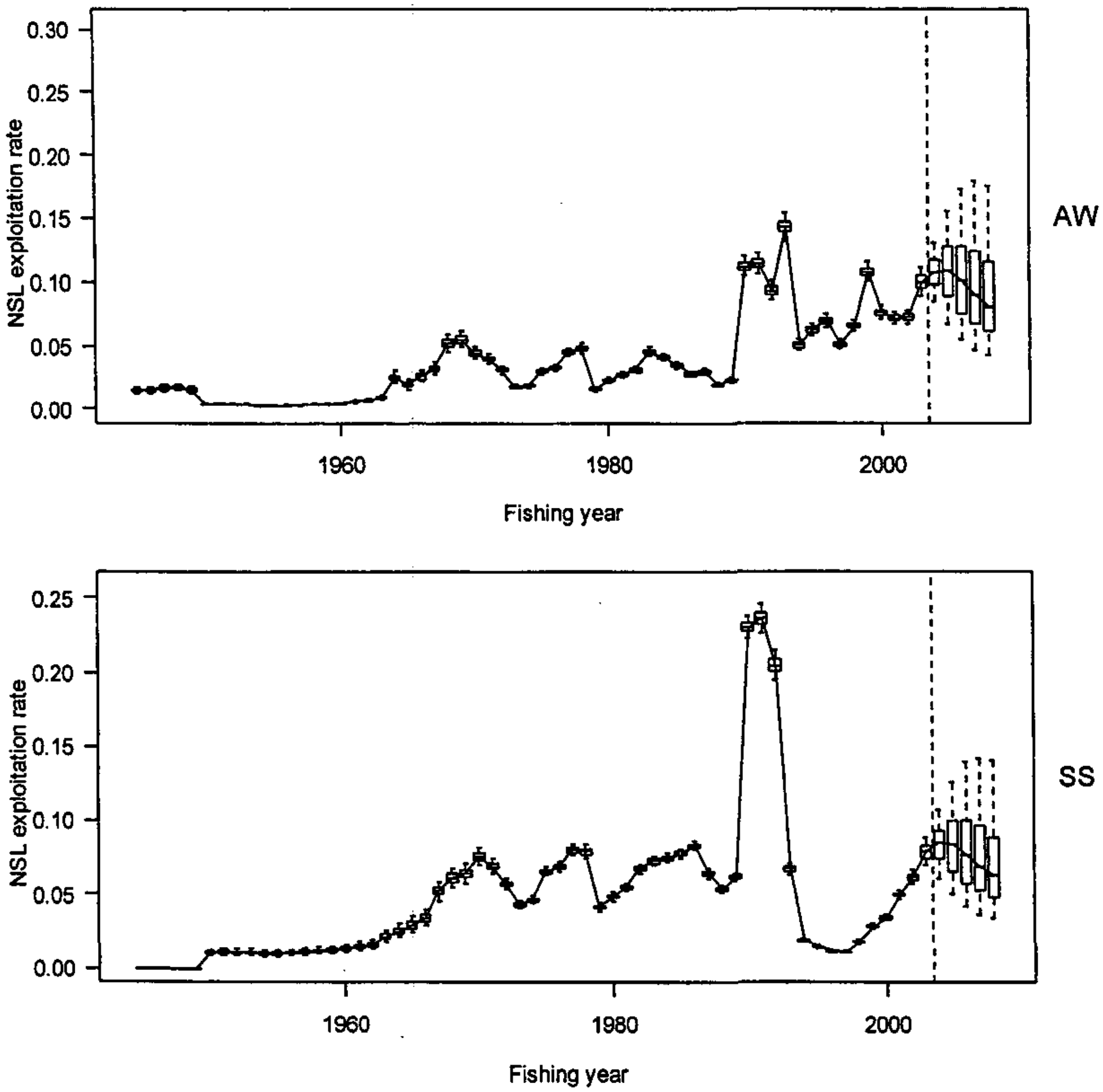


Figure 50: The posterior trajectories of NSL exploitation rate, by season, from the CRA 3 base case McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

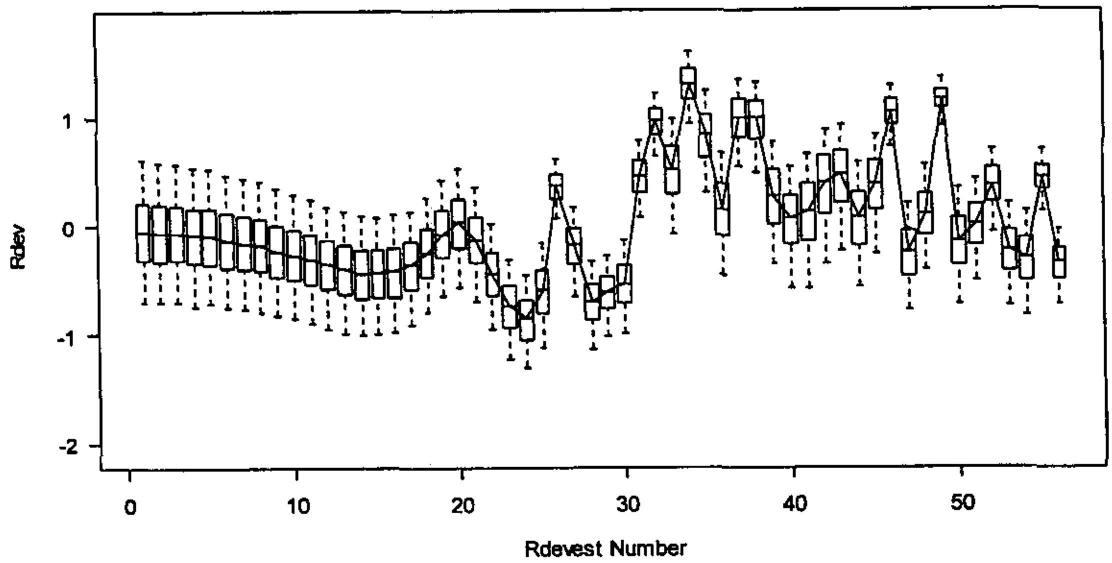


Figure 51: The posterior trajectory of recruitment deviations from the CRA 3 base case McMC simulations. For each deviation the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

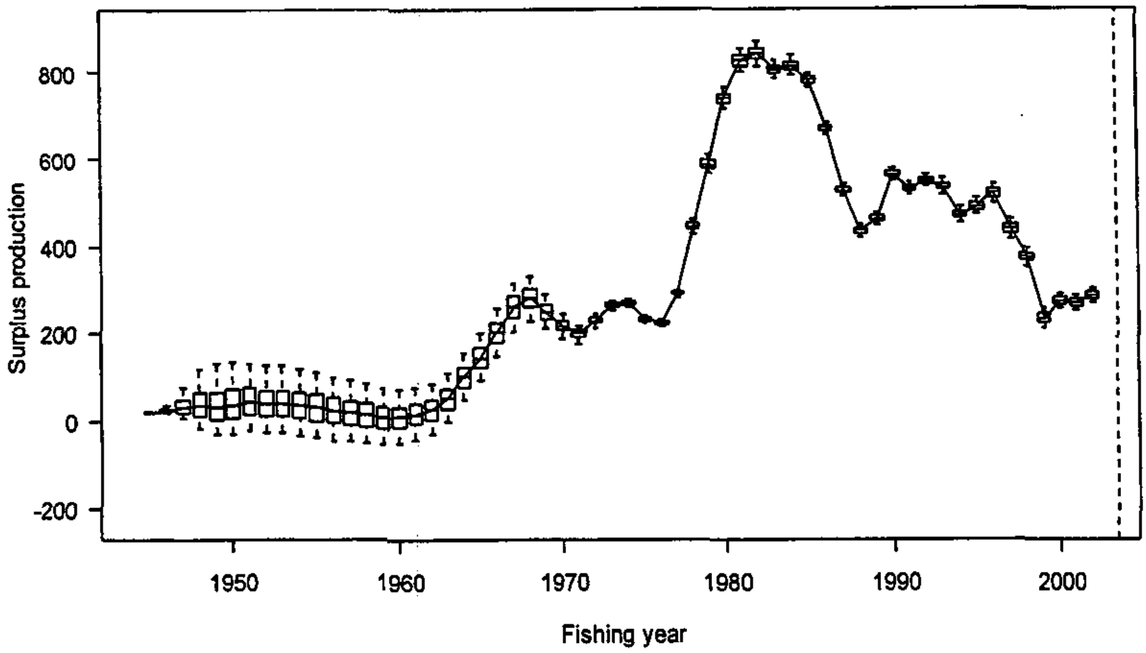


Figure 52: The posterior trajectory of surplus production from the CRA 3 base case McMC simulations. For each deviation the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

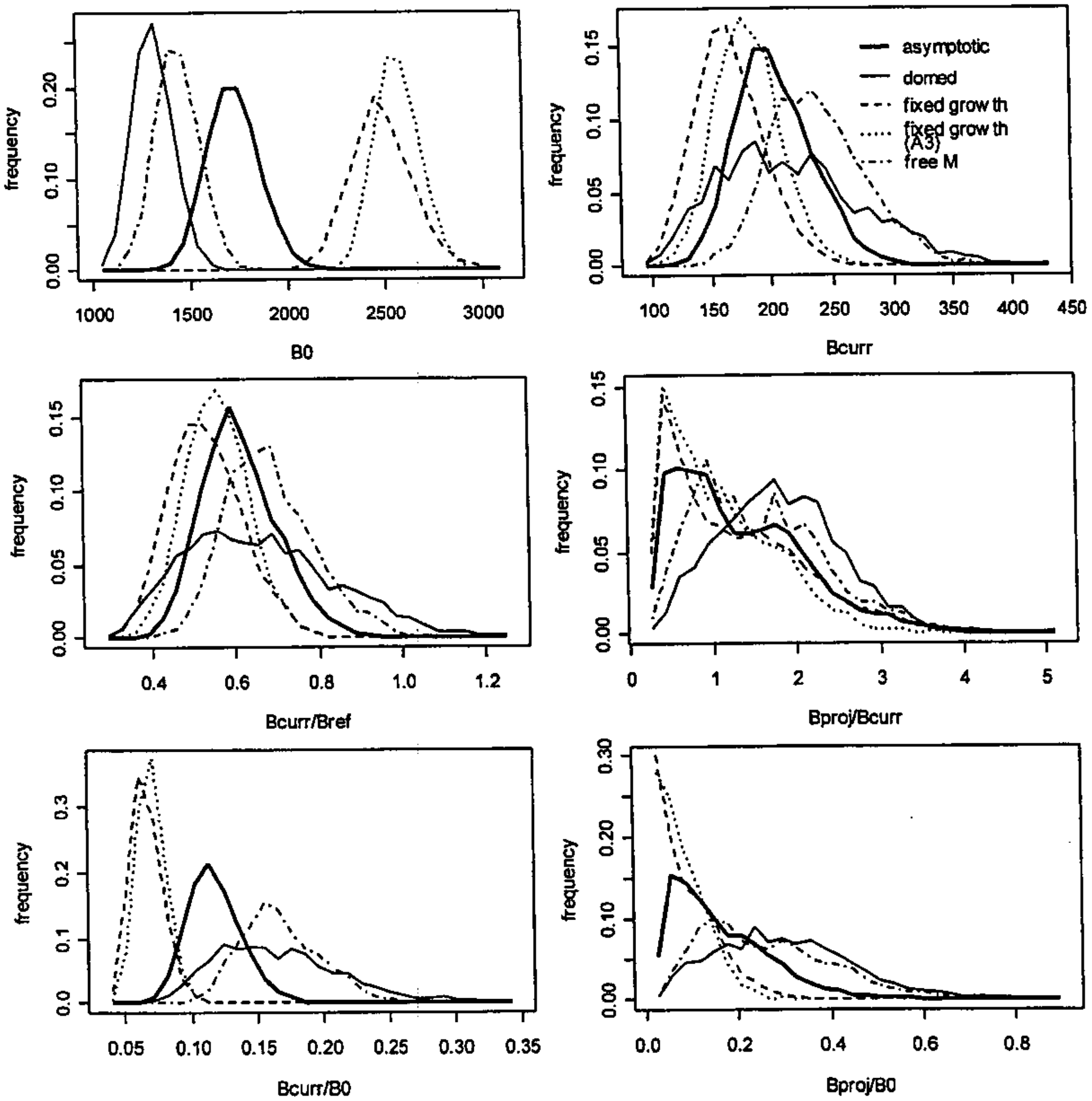


Figure 53: Comparison of posteriors from the CRA 3 base case and sensitivity trial McMC simulations. "Asymptotic refers to the base case. B0 is index biomass in 1945; Bcurr, current biomass; Bref, reference biomass; Bproj, projected biomass in AW 2007.

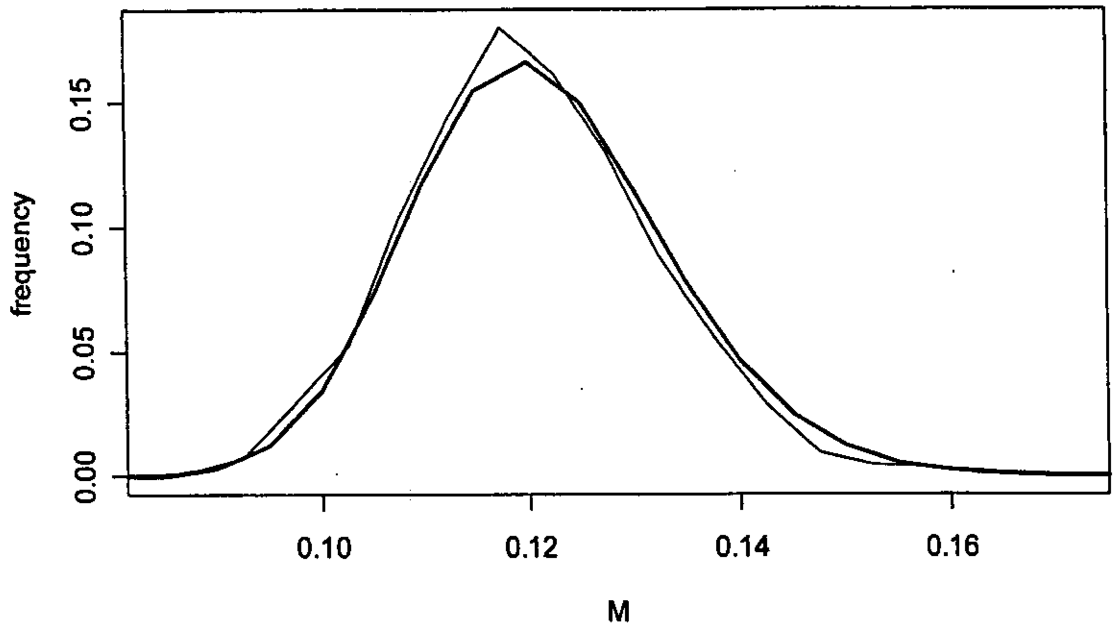


Figure 54: Prior distribution of *M* (heavy line) compared with the posterior distribution (light line) distribution from the "implicit prior" McMC simulations.

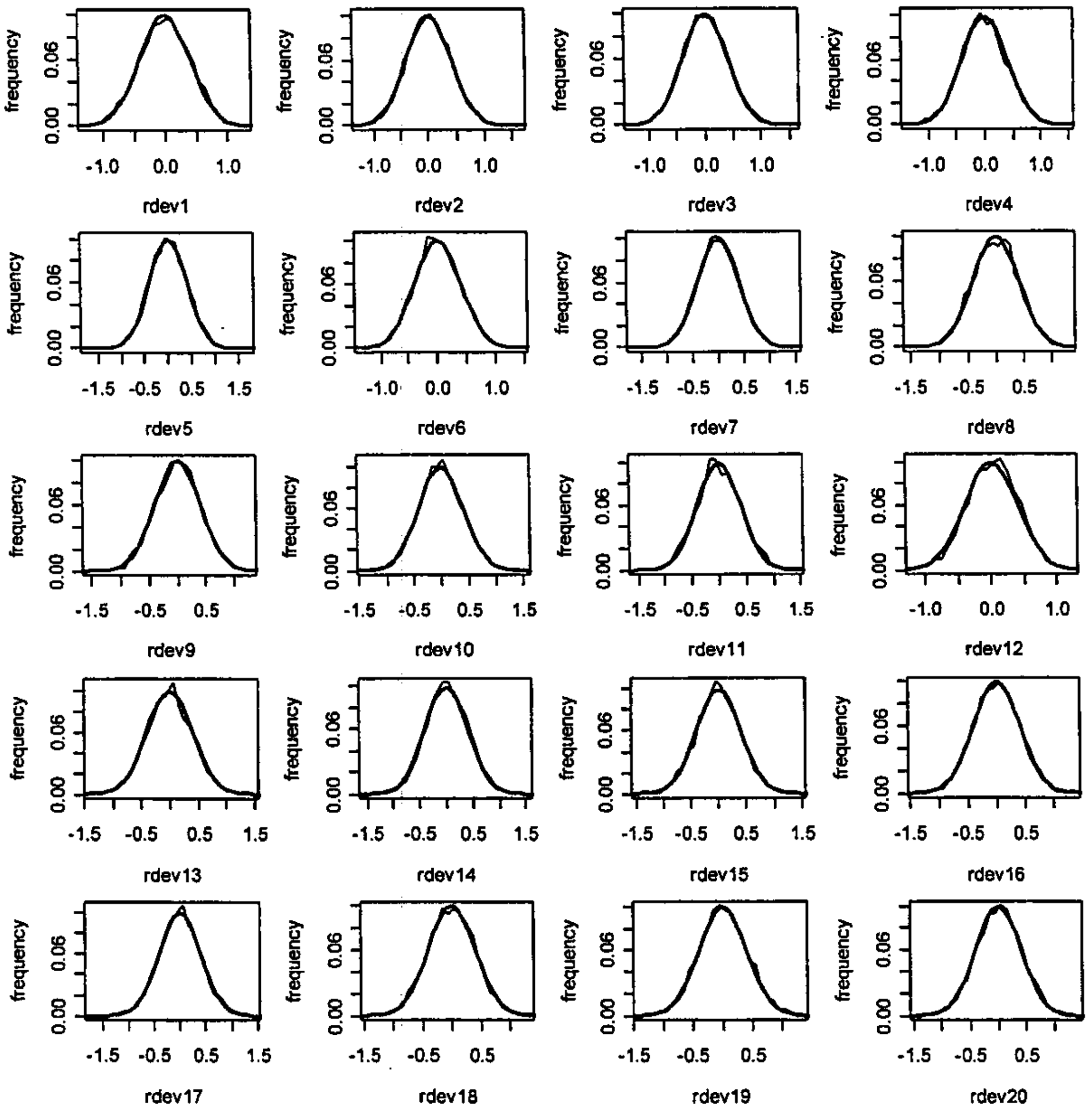
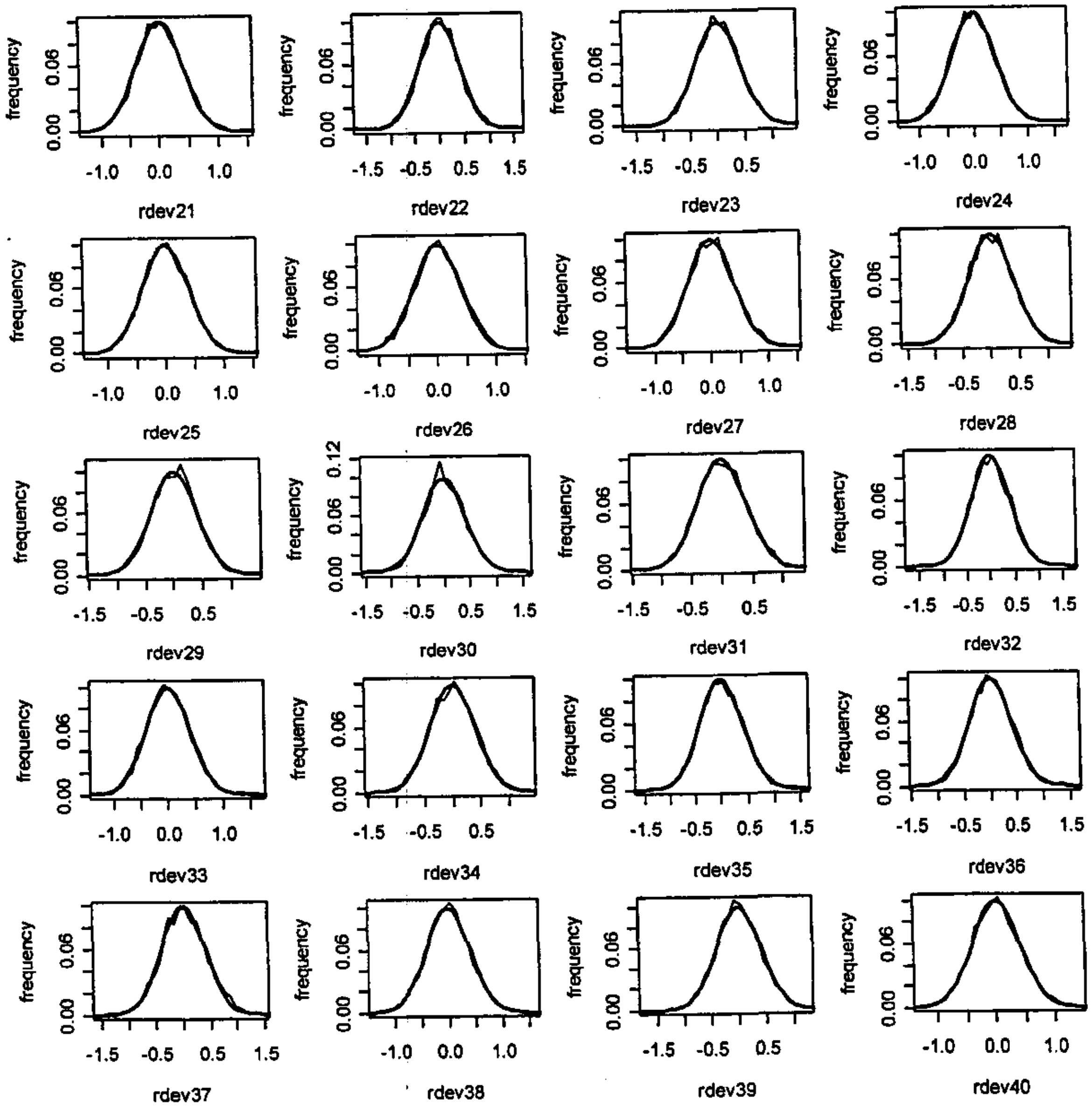


Figure 55: Prior distributions of *Rdevs* (heavy lines) compared with the posterior distributions (light lines) distribution from the "implicit prior" McMC simulations.



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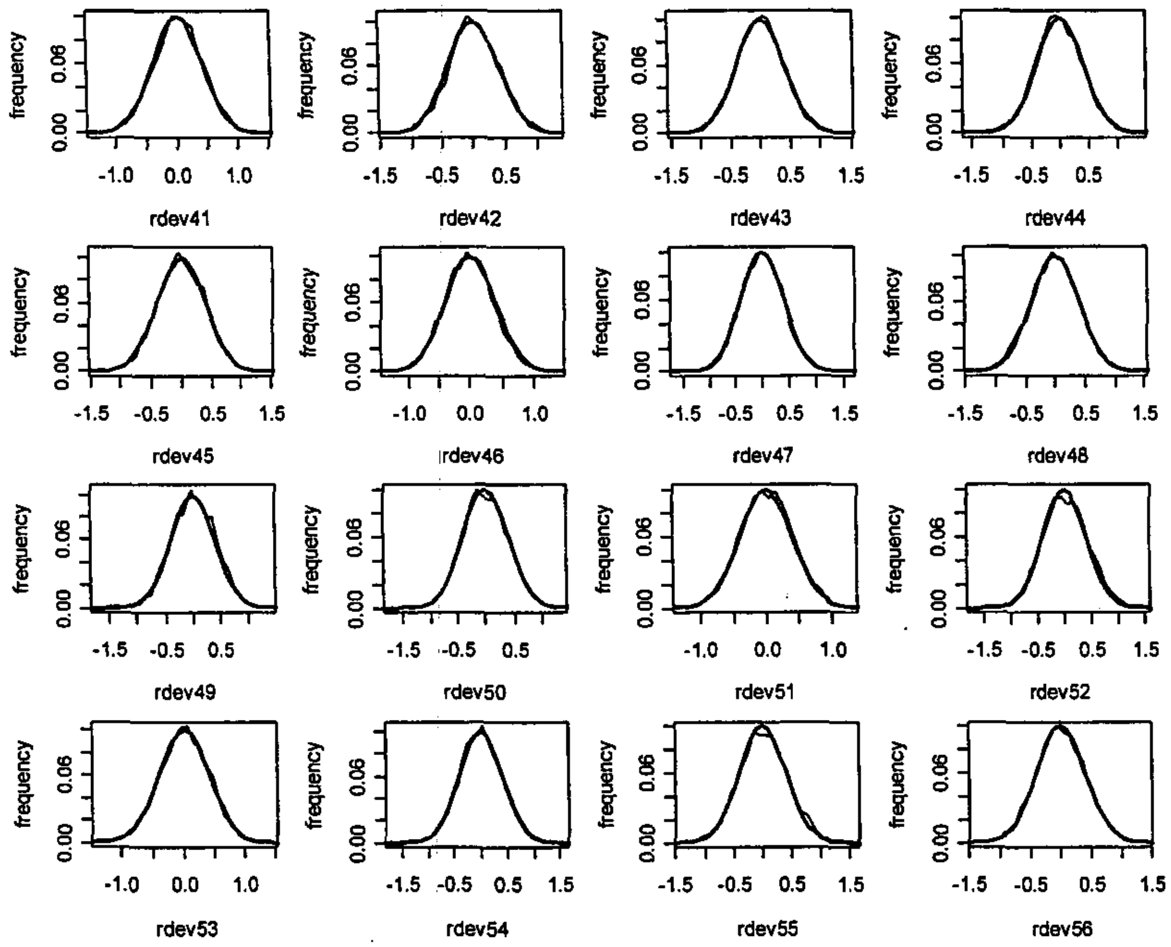


Figure 55: continued.

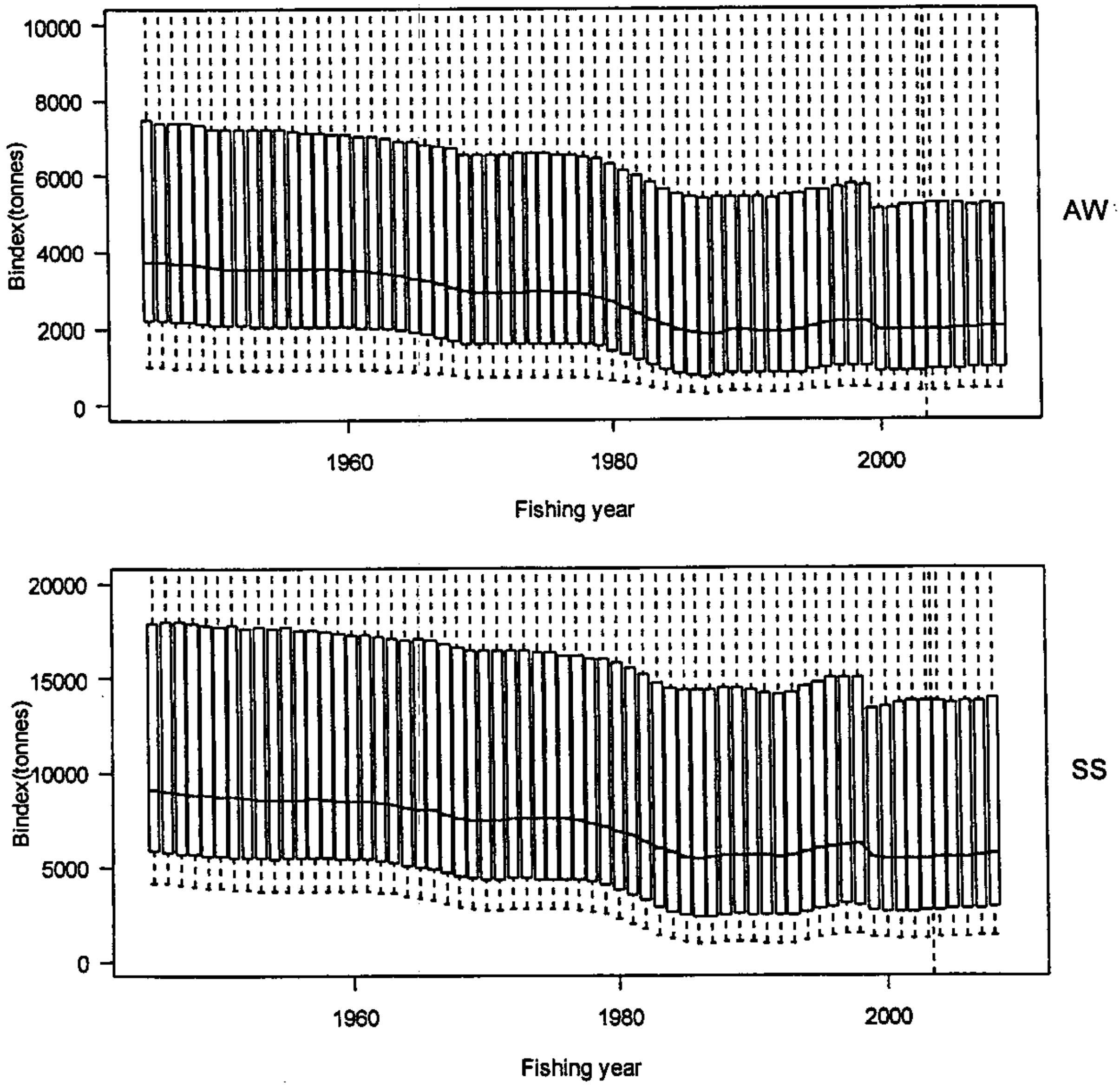


Figure 56: The posterior trajectory of index biomass, by season, from the implicit prior trial McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

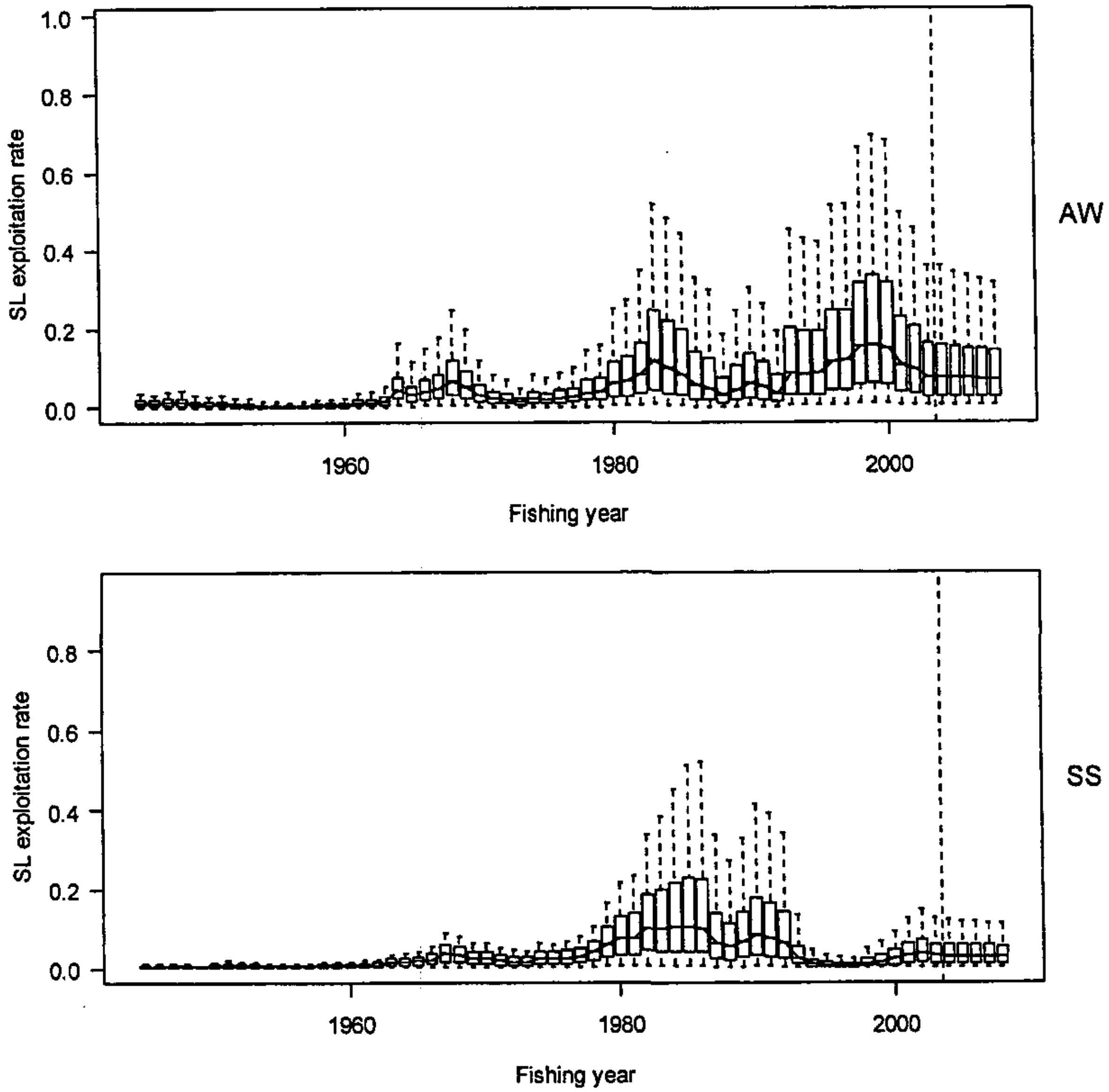
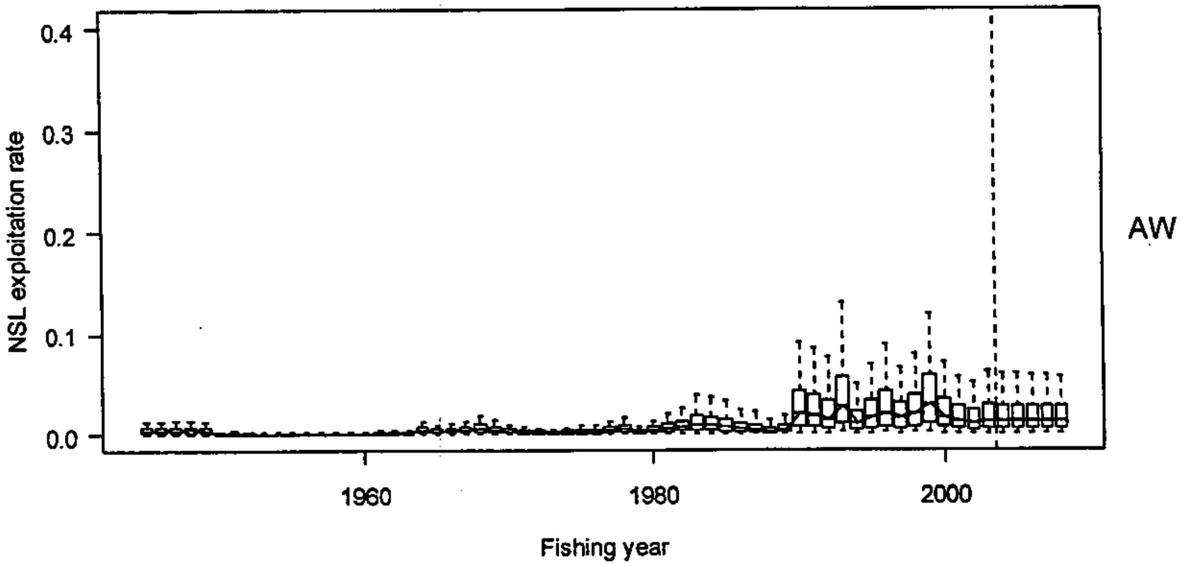


Figure 57: The posterior trajectories of SL exploitation rate, by season, from the implicit prior trial McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.



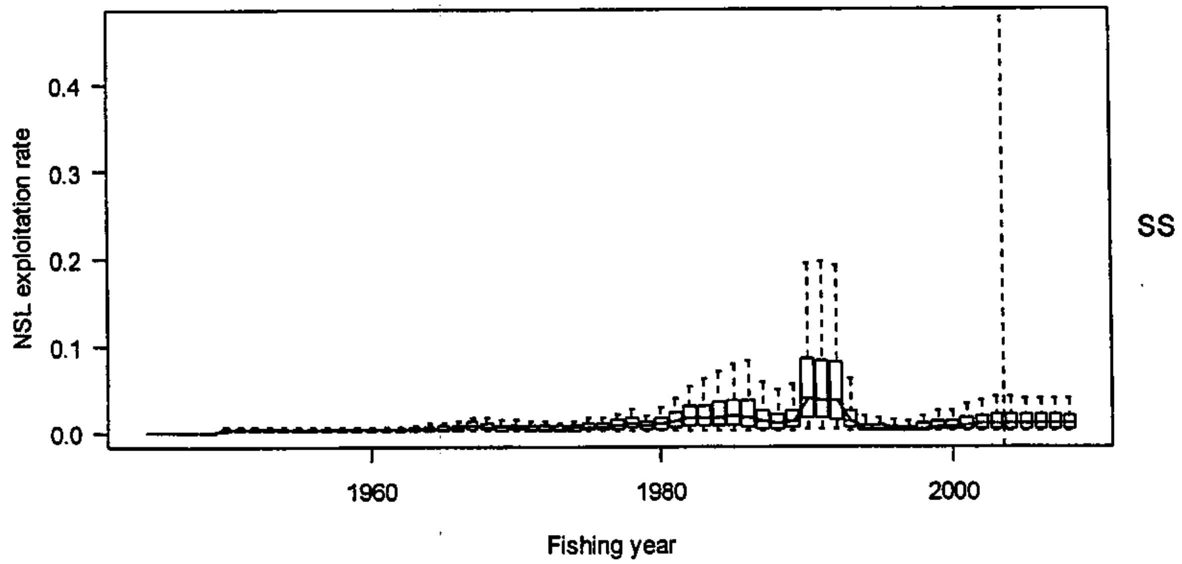


Figure 58: The posterior trajectories of NSL exploitation rate, by season, from the implicit prior trial McMC simulations. For each year the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

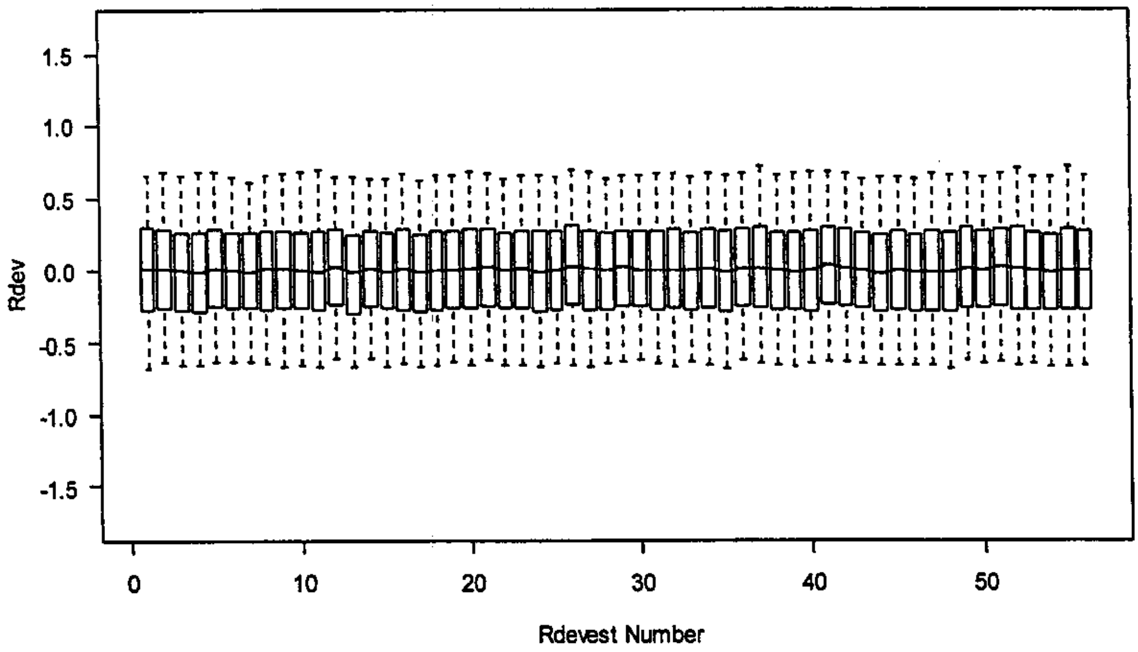


Figure 59: The posterior trajectory of recruitment deviations from the implicit prior trial McMC simulations. For each deviation the horizontal line represents the median, the box spans the 25th and 75th percentiles and the dashed whiskers span the 5th and 95th percentiles.

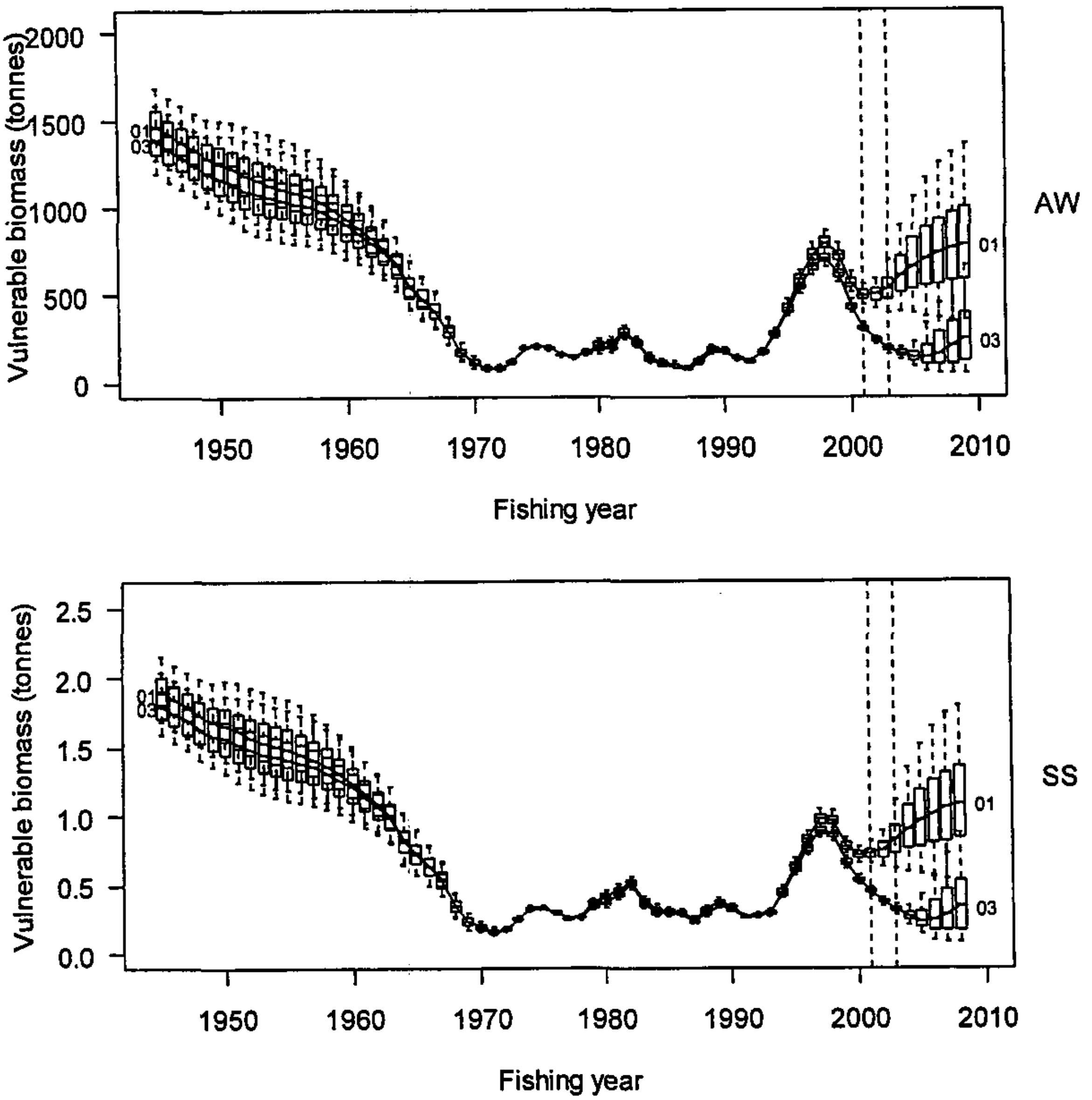


Figure 60: The posterior trajectories of vulnerable biomass, by season, from the base case (03) and retrospective (01) CRA 3 McMC simulations.

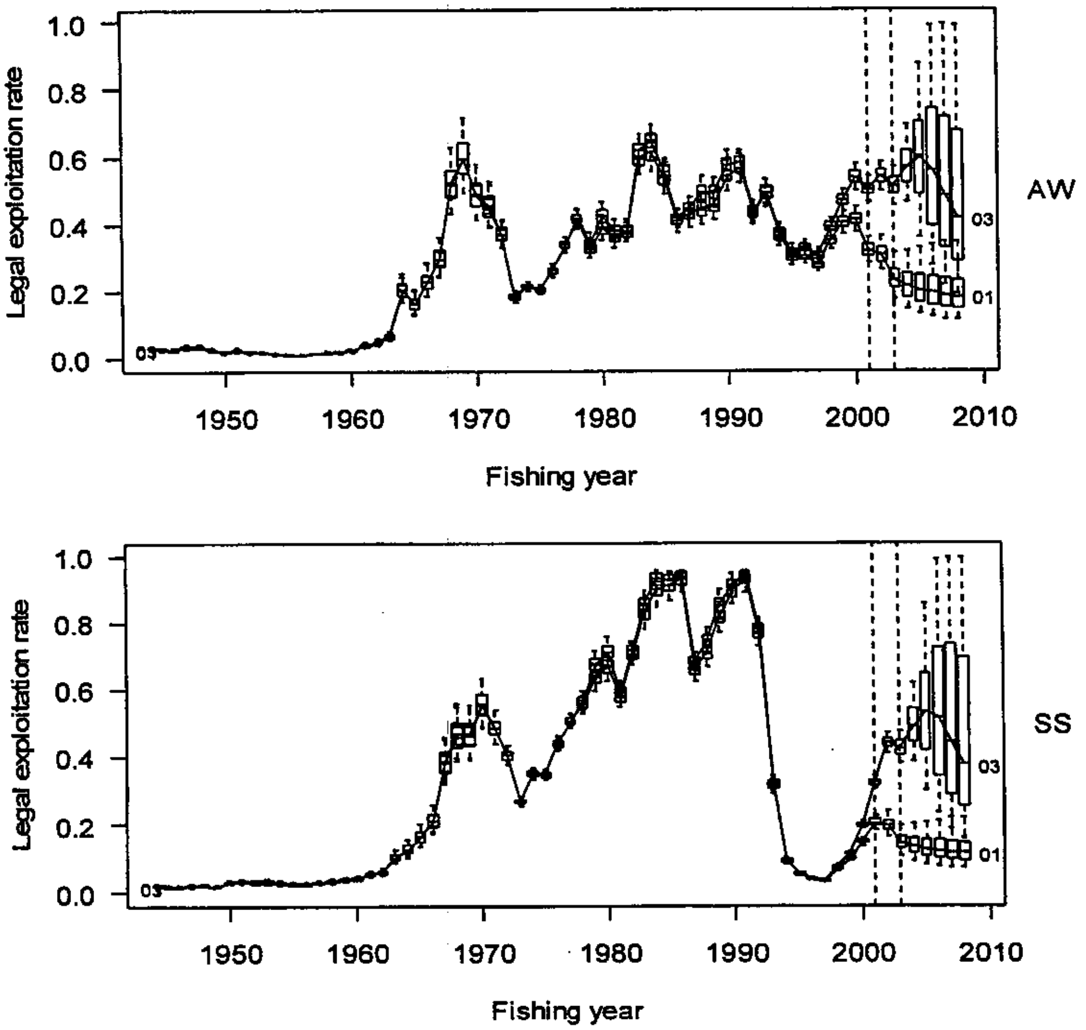


Figure 61: The posterior trajectories of SL exploitation rate from the base case (03) and retrospective (01) CRA 3 McMC simulations.

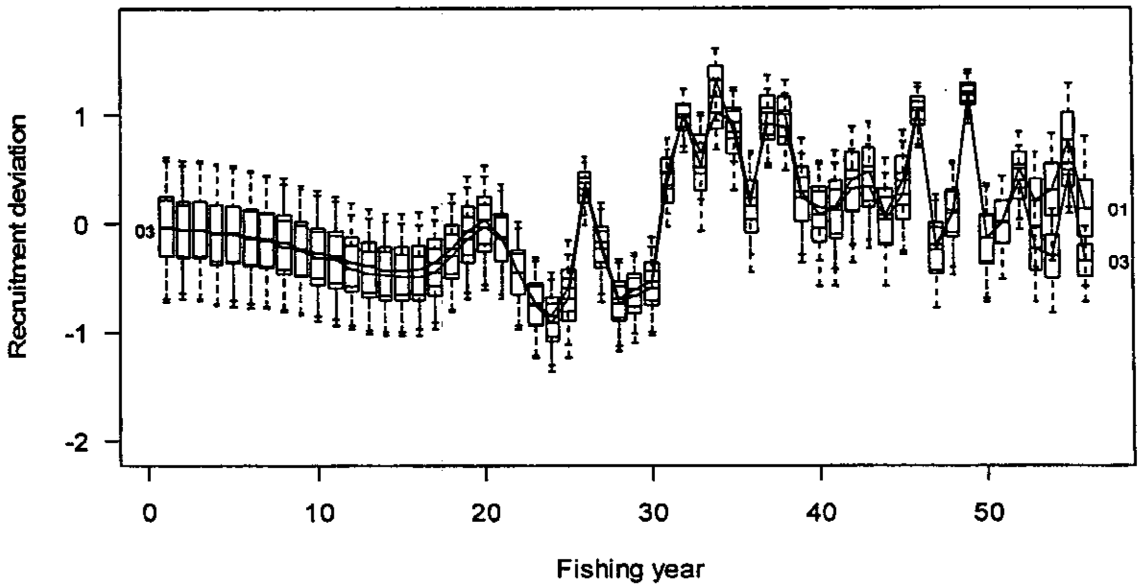


Figure 62: The posterior trajectories of legal exploitation rate from the base case (03) and retrospective (01) CRA 3 McMC simulations.

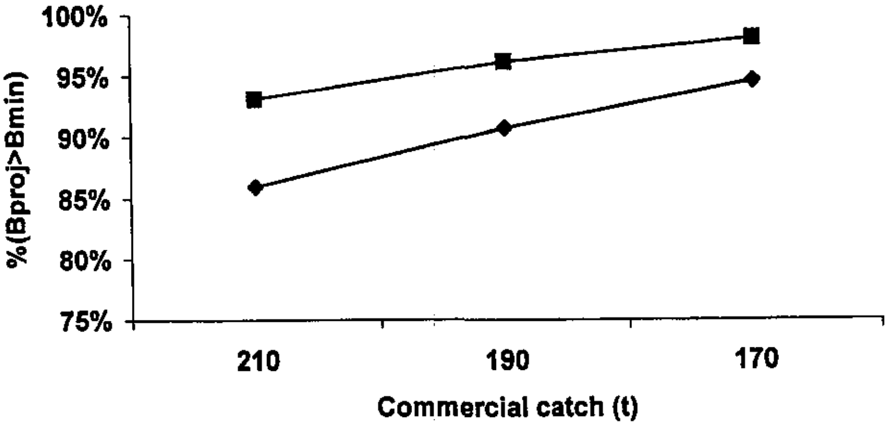


Figure 63: Percentage of runs in which *Bproj* was greater than *Bmin* under each commercial catch level, based on the CRA 3 base case McMC. In the runs in the lower line, the illegal catch was 89 t; for the upper line, illegal catch was 45 t.

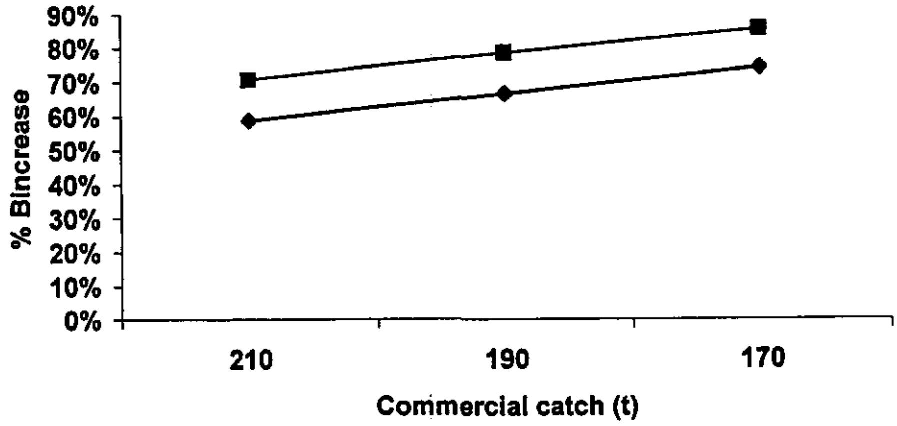


Figure 64: Percentage of runs in which *Bproj* was greater than *Bcurr* under each commercial catch level, based on the CRA 3 base case McMC. In the runs in the lower line, the illegal catch was 89 t; for the upper line, illegal catch was 45 t.

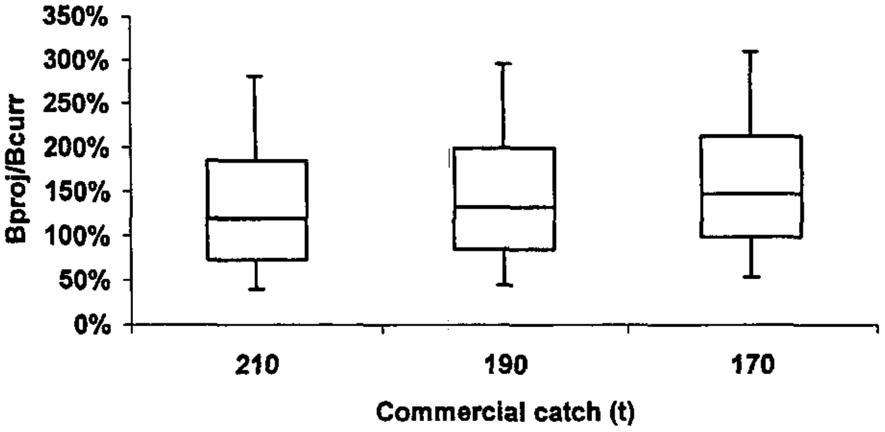


Figure 65: Posterior distributions of *Bproj/Bcurr* under each commercial catch level with 89 t of illegal catch based on the CRA 3 base case McMC. Box plot: the horizontal line is the median; the box encloses the 25 to 75th percentiles and the outer lines represent the 5th to 95th percentiles.

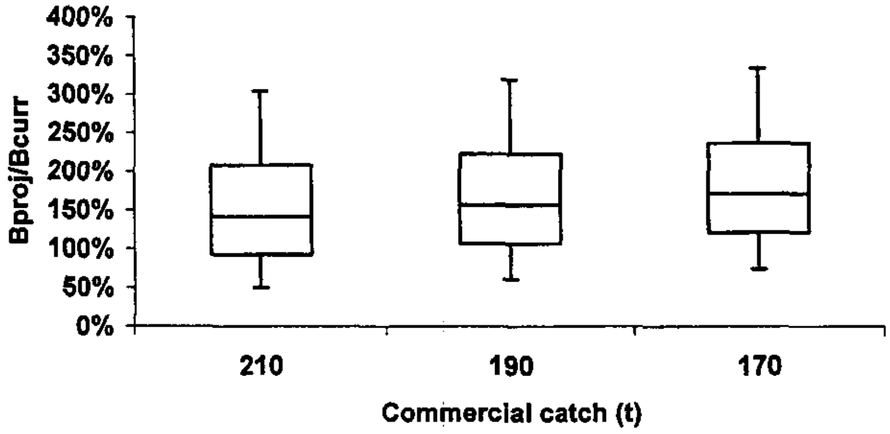


Figure 66: Posterior distributions of *Bproj/Bcurr* under each commercial catch level with 45 t of illegal catch based on the CRA 3 base case McMC. Box plot: the horizontal line is the median; the box encloses the 25 to 75th percentiles and the outer lines represent the 5th to 95th percentiles.

APPENDIX A. ASSESSMENT MODEL

The parameters and variables used by the model can be divided into the following.

- **Structural variables** that are fixed and define the structure of the model.
- **Observations** that are known and influence the history of the fishery in the model.
- **Model parameters** that influence the dynamics and that are either estimated or fixed at assumed values.
- **Derived variables** that are dependent on the model parameters and used to calculate state variables or to make predictions.
- **State variables,** dependent on model parameters, which describe the modelled state of the stock and are used to make model predictions.
- **Predictions** for comparison with observations
- **Likelihood variables** that are used in comparing the model's predictions with observations.

These parameters and variables are described in Table A1. The model uses a half-year time step: autumn-winter (AW) from 1 April to 30 September and spring-summer (SS) from 1 October to 31 March. Six-month periods are indexed by t. Season, indexed by k, can be calculated from t by $\mathrm{mod}(t-1,2)+1$.

Three sex categories, indexed by g, are kept distinct in the model: males (*male*), immature females (*female*), and mature females (*femmat*). Size classes are indexed by s, years by l, and tag return records by i. In describing how length frequency records are handled, month is indexed by m and area by o. In discussing how growth of tagged lobsters is predicted, the number of moults is indexed by j. The subscript used to index the selectivity function parameters is z.

Table A1: Major variables and parameters of the assessment model

Structural and fixed variables	
$\overset{\top}{S}_s$	Smallest size modelled in size class s
$\overset{\perp}{S}_s$	Largest size modelled in size class s
$\overline{S}_s$	Size of an individual in size class s (mid point of the size class bounds)
$s_{\max}$	Number of size classes modelled
a^g	Scalar of the size-weight relation for sex g
b^g	Exponent of the size-weight relation for sex g
w_s^g	Weight of an individual of size s and sex g
ϕ	Mode of the size distribution of recruits to the model
γ	Standard deviation of the size distribution of recruits
$\mathbf{I}$	Identity matrix for model size classes
λ	Shape parameter for mixing left and right halves of selectivity curves
$U^{\max}$	Maximum permitted exploitation rate in a period
f_k^g	Moult probability for sex g in season k
Observations	
C_t^{SL}	Catch limited by regulations in period t
C_t^{NSL}	Catch not limited by regulations in period t
I_t	Observed standardised CPUE in period t
CR_t	Observed historical catch rate in period t

I_t^{PR}	Observed pre-recruit index in period t
l_t^g	Minimum legal size limit for sex g in period t
$p_{s,t}^g$	Observed proportions-at-size in the catch in period t
$D_{m,o}$	Numbers of days sampled in month m and area o
$C_{m,o}$	Catch in month m and area a within a period
$c_{m,o}$	Calculated weight for length frequencies from month m and area o
$n_{m,o,s}^g$	Number of lobsters sampled in month m, area o and size s within a period
$p_{m,o,s}^g$	Proportion of lobsters sampled in month m, area o and size s within a period
κ_t	Calculated relative weight for proportions-at-size in period t
$S_i^{g,tag}$	Size and sex of the ith tagged lobster at release
$S_i^{g,recap}$	Size and sex of the ith tagged lobster at recapture

Estimated parameters

θ	Denotes the vector of model parameters
$\ln(R_0)$	Natural logarithm of R_0, the mean annual recruitment to the model for each sex in each period
ε_l	Recruitment deviation for year l
M	Instantaneous rate of natural mortality (per year)
r_k^g	Relative seasonal vulnerability for sex g and season k
$\ln(q^I)$	Natural logarithm of catchability for CPUE
$\ln(q^{CR})$	Natural logarithm of catchability for historical catch rates
$\ln(q^{PRI})$	Natural logarithm of catchability for pre-recruit indices
η_z^g	Size of maximum selectivity of sex g in selectivity epoch z
v_z^g	Shape parameter for the left hand limb of the selectivity curve of sex g in selectivity epoch z
w^g	Shape parameter for the right hand limb of the selectivity curve for sex g in all epochs
d_{50}^g	Mean expected moult increment for a lobster of size 50 mm TW and sex g
d_{50-80}^g	Difference between expected increments for lobsters of 50 and 80 mm TW for sex g
h^g	Shape parameter of the growth curve
CV^g	c.v. of the expected growth increment for sex g
$\varphi^{d,\min}$	Minimum standard deviation of the expected growth increment (sex-independent)
$\sigma^{d,obs}$	Standard deviation of the observation error in observed moult increments
m_{50}	Size at which the probability of a female maturing is 50%
m_{95-50}	Difference between sizes at 50% and 95% probability of a female maturing
χ	Determines shape of biomass-CPUE relation
$\tilde{\sigma}$	Component of error common to all data sets

Derived variables

$C_t^{NSL,BSL}$	Portion of C_t^{NSL} taken from B_t^{SL} in period t
$C_t^{NSL,BNSL}$	Portion of C_t^{NSL} taken from B_t^{NSL} in period t
$C_t^{total,BSL}$	Total catch taken from B_t^{SL} in period t
$F_{s,t}^g$	Legal status flag (zero or one) for individuals of sex g and size s in period t. Mature females are assumed to be berried and are therefore not legal in *AW*.
$\mathbf{R}_0$	Vector of average recruitment-at-size

$\mathbf{N}_0^g$	Vector of numbers-at-size for sex *g* in the unexploited population at equilibrium
x^g	Derived variable used for the growth increment calculation
y^g	Derived variable used for the growth increment calculation
d_s^g	Expected growth increment of an individual of size *s* and sex *g*
φ_s^g	Standard deviation of the growth increment for an animal of sex *g* and size *s*
$\mathbf{X}_k^g$	Growth transition matrix for sex *g* in season *k*
$X_{s,s',k}^g$	One cell of $\mathbf{X}_k^g$: the proportion of individuals of sex *g* that grow from size-class *s* to size-class *s'* in season *k*
$\hat{S}_{s,t+1}^g$	Expected size of an individual of size *s* and sex *g* after moulting
$V_{s,k,z}^g$	Total vulnerability, incorporating selectivity and seasonal vulnerability, of an individual of sex *g* and size *s* in epoch *z*
$T_{s,z}^g$	Intermediate term used in calculating $V_{s,k,z}^g$
$\mathbf{Q}$	Vector of the probability of females maturing-at-size
Q_s	Probability that an immature female at size *s* will become mature during period
P_t	Surplus production in period *t*

State variables

$N_{s,t}^g$	Numbers of sex *g* and size *s* at the start of period *t*
$N_{s,t+0.5}^g$	Numbers of sex *g* and size *s* in the mid-season of period *t*
$\dot{N}_{s,t}^g$	Numbers of sex *g* and size *s* after fishing in period *t*
$\ddot{N}_{s,t}^g$	Numbers of sex *g* and size *s* after fishing and natural mortality in period *t*
$\dddot{N}_{s,t}^g$	Numbers of sex *g* and size *s* after fishing, natural mortality, growth and recruitment in period *t*
R_t	Recruitment to the model (males and females, all sizes) in period *t*
$\mathrm{R}_{s,t}$	Recruitment to the model for size class *s* in period *t* (same for males and females)
B_t^{SL}	Biomass vulnerable to the SL fishery at the beginning of period *t*
B_t^{NSL}	Biomass vulnerable only to the NSL fishery at the beginning of period *t*
B_t^{total}	Sum of B_t^{SL} and B_t^{NSL} at the beginning of period *t*
U_t^{SL}	Exploitation rate on B_t^{SL} in period *t*
U_t^{NSL}	Exploitation rate on B_t^{NSL} in period *t*
H_t	Handling mortality rate in period *t*

Model predictions

$\hat{I}_t$	Predicted CPUE for period *t*
$C\hat{R}_t$	Predicted historical catch rate for period *t*
$\hat{I}_t^{PR}$	Predicted pre-recruit index for period *t*
$\hat{p}_{s,t}^g$	Predicted proportion-at-size for size *g* and sex *s* in period *t*
$\hat{S}_i^{g,recap}$	Predicted size at recapture for the *i*th tagged lobster
φ_i^g	Predicted standard deviation of the growth increment for the *i*th tagged lobster

Likelihood variables

σ^{ε}	Standard deviation of recruitment deviation

q^I	Scaling coefficient for CPUE index
σ_t^I	Standard deviation of standardised CPUE indices in period t
ϖ^I	Relative weight applied to CPUE likelihoods
q^{CR}	Scaling coefficient for catch rate index
σ^{CR}	Standard deviation of catch rate index
ϖ^{CR}	*Relative weight applied to historical catch rate likelihood*
q^{PRI}	Scaling coefficient for pre-recruit index
σ_t^{PRI}	Standard deviation of standardised pre-recruit indices in period t
ϖ^{PRI}	Relative weight applied to PRI likelihoods
ϖ^{p}	Relative weight applied to proportions-at-size
ϖ^{TAG}	Relative weight applied to tagging data

A.1 Initial size structure

The population is assumed to be in an initial unexploited equilibrium, in this case at the start of period 1, AW 1945. The number of each sex in each size class is the equilibrium function of the growth transition matrices for each season, recruitment, and natural mortality:

Eq 1

$$\mathbf{N}_0^{male} = \left[1+\mathbf{X}_{AW}^{male} e^{-0.5M}\right]\left[\mathbf{R}_0\left(\mathbf{I}-\mathbf{X}_{AW}^{male}\mathbf{X}_{SS}^{male}\left(e^{-0.5M}\right)^2\right)^{-1}\right]$$

$$\mathbf{N}_0^{female} = \left[1+\mathbf{X}_{AW}^{female} e^{-0.5M}(1-\mathbf{Q})\right]\left[\mathbf{R}_0\left(\mathbf{I}-\mathbf{X}_{AW}^{female}\mathbf{X}_{SS}^{female}\left(e^{-0.5M}\right)^2(1-\mathbf{Q})^2\right)^{-1}\right]$$

$$\mathbf{N}_0^{femmat} = \left[1+\mathbf{X}_{AW}^{female} e^{-0.5M}\right]\left[\mathbf{R}_0\left(\mathbf{I}-\mathbf{X}_{AW}^{female}\mathbf{X}_{SS}^{female}\left(e^{-0.5M}\right)^2\right)^{-1}\right]-\mathbf{N}_0^{female}$$

where the vector of recruitment-at-size, $\mathbf{R}_0$ (same for males and females), is derived from the multiplication of R_0 and the equilibrium recruitment proportions-at-size, calculated as in Eq 26, $\mathbf{X}_{SS}^{g}$ and $\mathbf{X}_{AW}^{g}$ are growth transition matrices for spring-summer and autumn-winter for sex g and $\mathbf{Q}$ is *the vector of the probability of females maturing-at-size.*

A.2 Overview of dynamics

The dynamics proceeds in a series of steps through each time step, the 6-month period. First, the biomass vulnerable to fishing is calculated from number-at-size, weight-at-sex, selectivity-at-size and relative seasonal vulnerability, all for each sex. This is done twice – once for the fishery that respects the size limit and berried female restrictions (the SL fishery) and once for the fishery that does not (the NSL fishery).

From biomass and the observed SL and NSL catches, exploitation rates are calculated; if they exceed the assumed maximum value $U^{\max}$ they are reduced to $U^{\max}$ and the model's function value is penalised. Then the two fisheries are simulated, reducing numbers-at-size in two steps to obtain the mid-season numbers and the post-fishing numbers.

After fishing, growth is simulated, recruitment is calculated and added to the vector of numbers-at-size, and then maturation of immature to mature females is simulated, giving the numbers at the beginning of the next period.

A.3 Selectivity and relative vulnerability

The ascending and descending limbs of the selectivity curve are modelled using halves of two normal curves with the same mean but with different shapes, one for the left half and one for the right. These are determined by parameters analogous to the variance of a normal curve. This is sometimes called a "double-normal" but is really a "bi-hemi-normal" curve. A logistic selectivity curve can be approximated by setting the shape parameter for the right hand limb to a large number.

The model can calculate different curves for each of a number of epochs, for instance, if the MLS or escape gap regulations change, in this study 2 epochs were used. Total vulnerability is the product of the selectivity curve and the relative seasonal vulnerability for each sex, r_k^g:

Eq 2

$$V_{s,k,z}^{g} = r_k^{g}\left[\left(1-T_{s,z}^{g}\right)e^{\frac{\ln 0.5\left(\bar{S}_s^{g}-\eta_z^{g}\right)^2}{\left(v_z^{g}\right)^2}} + T_{s,z}^{g}e^{\frac{\ln 0.5\left(\bar{S}_s^{g}-\eta_z^{g}\right)^2}{\left(w^{g}\right)^2}}\right]$$

$$T_{s,z}^{g} = 1/\left(1+\exp\left(-\left(\bar{S}_s^{g}-\eta_z^{g}\right)\lambda\right)\right)$$

Selectivity curves are assumed to be the same for mature and immature females. A switch allows maximum seasonal vulnerability to any sex/season combination and it is assumed that the relative seasonal vulnerability of mature females differs from that of immature females only in autumn-winter, i.e. $r_{SS}^{femmat} = r_{SS}^{female}$. The normal assumption is that males in spring-summer have the maximum vulnerability, but this can be varied to any sex/season combination (Table A2).

Table A2: Switch values and the assumed sex/season with maximum relative vulnerability.

Switch	Vulnerability
1	r_{SS}^{male}
2	r_{AW}^{male}
3	r_{AW}^{female}
4	r_{SS}^{female}
5	r_{AW}^{femmat}

A.4 Vulnerable biomass

The model must simulate two kinds of fishing: fishing that takes all vulnerable lobsters, and fishing that takes only those that are both above the MLS and not berried females. The first fishery includes the illegal and Maori customary fisheries; Maori customary fishing is not illegal so this fishery cannot simply be called the illegal fishery, and we call it the NSL fishery. The other fishery, governed by the regulations, comprises the commercial and recreational fisheries, and we call it the SL fishery.

The total biomass vulnerable to the NSL fishery at any time is the product of numbers, weight, and vulnerability-at-size:

Eq 3 $$B_t^{total} = \sum_g \sum_s N_{s,t}^g W_s^g V_{s,k,z}^g$$

where mean weight of individuals in each size class is determined from:

Eq 4 $$W_s^g = a^g \left(\bar{S}_s\right)^{b^g}$$

The a^g and b^g parameters are assumed to be the same for immature and mature females. The legal switch $F_{s,t}^g$ for the SL fishery is determined by comparing size with the minimum legal size:

Eq 5 $$F_{s,t}^g = \begin{cases} 0 & \bar{S}_s \le S_{g,t}^{MLS} \\ 1 & \bar{S}_s > S_{g,t}^{MLS} \end{cases}$$

and $F_{s,t}^g$ is zero for all mature females in the autumn-winter season. The SL biomass is

Eq 6 $$B_t^{SL} = \sum_g \sum_s N_{s,t}^g W_s^g V_{s,k,z}^g F_{s,t}^g$$

The biomass vulnerable **only** to the NSL fishery is

Eq 7 $$B_t^{NSL} = B_t^{total} - B_t^{SL} = \sum_g \sum_s N_{s,t}^g W_s^g V_{s,k,z}^g \left(1 - F_{s,t}^g\right)$$

A.5 Exploitation rates

The observed catches are partitioned in the data file into catches from the two fisheries: C_t^{SL} and C_t^{NSL}. Exploitation rate is calculated as catch over biomass. The model must calculate the total exploitation rate expended by both fisheries on the biomass available to the SL fishery, and limit it if necessary. The portion of C_t^{NSL} to be taken from the SL biomass is

Eq 8 $$C_t^{NSL,BSL} = \frac{C_t^{NSL} B_t^{SL}}{B_t^{total}}$$

and from the NSL biomass is

Eq 9 $$C_t^{NSL,BNSL} = \frac{C_t^{NSL} B_t^{NSL}}{B_t^{total}} = C_t^{NSL} - C_t^{NSL,BSL}$$

The total catch to be taken from the SL biomass is the sum of components from the two fisheries

Eq 10 $$C_t^{total,BSL} = C_t^{NSL,BSL} + C_t^{SL}$$

Total catch from the NSL biomass is $C_t^{NSL,BNSL}$.

Now the model can calculate, and limit if necessary, the exploitation rates applied to these two components of the population. The exploitation rate applied to the SL biomass is

Eq 11 $$U_t^{SL} = \frac{C_t^{total,BSL}}{B_t^{SL}}$$

and to the NSL biomass is

Eq 12 $$U_t^{NSL} = \frac{C_t^{NSL,BNSL}}{B_t^{NSL}}$$

If U_t^{SL} exceeds a value specified, U^{max}, 0.90 for this assessment, then U_t^{SL} is restricted to just over U^{max} with the AD Model Builder™ *posfun* and a large penalty is added to the total negative log-likelihood function. This keeps the model away from parameter combinations that do not allow the catch to have been taken. U_t^{NSL} is similarly limited.

Handling mortality is exerted by the SL fishery on vulnerable animals returned to the water because they are under-sized or berried females. This is assumed to be a constant proportion (0.1) of the exploitation rate exerted by the SL fishery:

Eq 13 $$H_t = 0.1\frac{C_t^{SL}}{B_t^{SL}}.$$

This is reduced proportionally if *posfun* has reduced the exploitation rate and C_t^{SL}.

A.6 Fishing mortality

Fishing mortality from the SL, NSL and handling mortality are applied simultaneously to the population. This occurs in two steps so that mid-season biomass and mid-season size structures can be calculated. The numbers at mid-season are calculated from numbers at the start of the period, using half the exploitation rates described above:

Eq 14 $$N^g_{s,t+0.5} = N^g_{s,t}\left[1-0.5\left(U_t^{NSL}+H_t\right)V^g_{s,k,z}\left(1-F^g_{s,t}\right)\right]\left[1-0.5U_t^{SL}V^g_{s,k,z}\left(F^g_{s,t}\right)\right]$$

The model then re-calculates vulnerable biomass in each category, re-calculates the exploitation rate required to take the remaining catch (if *posfun* reduced the exploitation rate, the required catch was reduced proportionally), and calculates numbers after all fishing in the period:

Eq 15 $$\dot{N}^g_{s,t} = N^g_{s,t+0.5}\left[1-\left(U^{NSL}_{t+0.5}+H_{t+0.5}\right)V^g_{s,k,z}\left(1-F^g_{s,t}\right)\right]\left[1-U^{SL}_{t+0.5}V^g_{s,k,z}\left(1-F^g_{s,t}\right)\right]$$

A.7 Natural mortality

Natural mortality is applied to numbers after all fishing has taken place in a period:

Eq 16 $$\ddot{N}^g_{s,t} = \dot{N}^g_{s,t}e^{-0.5M}.$$

A.8 Growth

Moult-based growth is modelled explicitly using a two part model. The first part of the model describes the sex- and size-specific moult increment of a lobster in size class s. The parameters of the model are d_α^g and d_β^g, the expected increments for lobsters of size α (50 mm) and β (80 mm) TW for sex g, and h^g, a shape parameter for sex g. Instead of d_β^g we estimate $d_{\alpha-\beta}^g$, the difference between growth at 50 and 80 mm, to constrain d_β^g to be less than d_α^g.

Define two new variables as functions of these 5 variables:

Eq 17 $$x^g = \left(\beta^{h^g} - \alpha^{h^g}\right) \Big/ \left(\left(\beta + d_\beta^g\right)^{h^g} - \left(\alpha + d_\alpha^g\right)^{h^g}\right)$$

and

Eq 18 $$y^g = \frac{\left(\beta^{h^g}\left(\alpha + d_\alpha^g\right)^{h^g} - \alpha^{h^g}\left(\beta + d_\beta^g\right)^{h^g}\right)}{\left(\left(\alpha + d_\alpha^g\right)^{h^g} - \alpha^{h^g} + \beta^{h^g} - \left(\beta + d_\beta^g\right)^{h^g}\right)}$$

The mean predicted increment for length l_s is:

Eq 19 $$d_s^g = -\overline{S}_s + \left[\frac{\overline{S}_s^{\,h^g}}{x^g} + y^g\left(1 - \frac{1}{x^g}\right)\right]^{\left(1/h^g\right)}$$

but is constrained with the AD Model Builder™ *posfun* function to be positive.
Variability in the growth increment is assumed to be normally distributed around d_s^g with a standard deviation φ_s^g that is a constant proportion the expected increment, but is truncated at a minimum value $\varphi^{d,\min}$. The equation below is used to give a smooth differentiable function:

Eq 20 $$\varphi_s^g = \left(j_s^g CV^g - \varphi^{d,\min}\right)\left(\frac{1}{\pi} \times \tan^{-1}\left(\left(d_s^g CV^g - \varphi^{d,\min}\right) \times 10^6\right) + 0.5\right) + \varphi^{d,\min}$$

The second part of the growth model describes the sex- and size-specific probability of moulting. Males are assumed to moult in both seasons; females are assumed to moult only at the beginning of the AW season. The seasonal moult probability f_k^g is set to zero or one, depending on the sex and season as just described.

From this growth model, the growth transition matrix $\mathbf{X}_k^g$ is generated as follows. The expected size, after moulting, of an individual of sex g and size $\overline{S}_s^g$ (in size class s) is:

Eq 21 $$\hat{S}_{s,t+1}^g = \overline{S}_s + d_s^g f_k^g$$

Because of variability in growth, not all individuals move into the size class containing $\hat{S}_{s,t+1}^g$; some move into smaller or larger size classes, depending on φ_s^g. For each size class s, the probability that the individual will grow into each of the other size classes, s', is calculated by integrating over a normal distribution with mean $\hat{S}^{g}_{s,t+1}$ and standard deviation φ^{g}_{s}. The largest size group is cumulative, i.e., no animals grow out of this group, so the integration is done from the smallest size in that size class, $\bar{S}_{s'}$ to ∞. With the sex index, *g*, and the season index, *k*, suppressed this is:

Eq 22
$$X_{s,s'} = \begin{cases} \int_{\bar{S}_{s'}}^{\bar{S}_{s'}} \frac{1}{\sqrt{2\pi\varphi_s}} \exp\left(-\frac{\left(\bar{S}_s - \hat{S}_{s,t+1}\right)^2}{2\left(\varphi_s\right)^2} \right) \partial S & \text{if } s' < s_{\max} \\ \int_{\bar{S}_{s'}}^{\infty} \frac{1}{\sqrt{2\pi\varphi_s}} \exp\left(-\frac{\left(\bar{S}_s - \hat{S}_{s,t+1}\right)^2}{2\left(\varphi_s\right)^2} \right) \partial S & \text{if } s' = s_{\max} \end{cases}$$

Moulting in this model occurs at the beginning of each period. Growth is applied to the numbers remaining in each size class after fishing and natural mortality, $\ddot{N}^{g}_{s,t}$:

Eq 23
$$\ddot{N}^{g}_{s',t} = \sum_{s} \left(X^{g}_{s,s'} . \ddot{N}^{g}_{s,t} \right) + R_{s',t+1}$$

for males and females, where $R_{s',t+1}$ is calculated as described below. For mature females:

Eq 24
$$\ddot{N}^{femmat}_{s',t} = \sum_{s} \left(X^{femmat}_{s,s'} \ddot{N}^{femmat}_{s,t} \right)$$

A.9 Recruitment

The number of lobsters recruiting to the model in a year is assumed to be equal for males and females and is divided equally over the two seasons. Recruitment deviations are estimated for those years likely to have information on the strength of recruitment, and total recruitment is calculated from:

Eq 25
$$R_t = 0.5 R_0 e^{\left[\varepsilon_t - \frac{\left(\sigma^{\varepsilon}\right)^2}{2} \right]}$$

where it is assumed that the recruitment deviations ε_t are normally distributed with mean zero and standard deviation σ^{ε}. The term $-\frac{\left(\sigma^{\varepsilon}\right)^2}{2}$ corrects for the log-normal bias associated with different values of σ^{ε}.

Recruitment is dispersed over the size-classes, assuming a normal distribution truncated at the smallest size class:

Eq 26 $$R_{s,t} = R_t \frac{\exp\left(-(\bar{S}_s-\phi)^2 \big/ 2\gamma^2\right)}{\sum_s \exp\left(-(\bar{S}_s-\phi)^2 \big/ 2\gamma^2\right)}$$

where $\bar{S}_s$ is the mean size in size class s, ϕ is the (assumed) mean size-at-recruitment and γ is the (assumed) standard deviation about mean size-at-recruitment.

A.10 Maturation

The probability of a female maturing during a period is modelled as a logistic curve:

Eq 27 $$Q_s = \frac{1}{1+\exp\left[-\ln(19)\left(\bar{S}_S - m_{50}\right) \big/ \left(m_{95-50}\right)\right]}$$

Maturation occurs after growth, and this determines the numbers at the beginning of the next period. Males are not involved:

Eq 28 $$N^{male}_{s,t+1} = \ddot{N}^{male}_{s,t}$$

Immature females that mature are subtracted from the number of immature females in size class s:

Eq 29 $$N^{female}_{s,t+1} = \ddot{N}^{female}_{s,t}\left(1-Q_s\right)$$

and added to the number of mature females in size class s:

Eq 30 $$N^{femmat}_{s,t+1} = \ddot{N}^{femmat}_{s,t} + Q_s \ddot{N}^{female}_{s,t}$$

A.11 Predictions and likelihoods for abundance indices

The predicted CPUE index is calculated from mid-season vulnerable biomass:

Eq 31 $$\hat{I}_t = e^{\ln\left(q^I\right)}\left(B^{SL}_{t+0.5}\right)^{\chi}$$

where χ determines the shape of the relationship and the scaling coefficient $\ln\left(q^I\right)$ is an estimated parameter.

A log-normal likelihood function is used to compare predicted ($\hat{I}_t$) and observed (I_t) biomass indices,

Eq 32 $$L\left(\hat{I}_t \mid \theta\right) = \frac{\varpi^I}{I_t \sigma^I_t \tilde{\sigma}\sqrt{2\pi}} \exp\left[\frac{-\left(\ln(I_t) - \ln(\hat{I}_t) + 0.5\left(\sigma^I_t \tilde{\sigma} / \varpi^I\right)^2\right)^2}{2\left(\sigma^I_t \tilde{\sigma} / \varpi^I\right)^2}\right].$$

The normalised residual is:

Eq 33 $$residual = \frac{\ln(I_t) - \ln(\hat{I}_t) + 0.5\left(\sigma_t^I \tilde{\sigma} / \varpi^I\right)^2}{\left(\sigma_t^I \tilde{\sigma} / \varpi^I\right)}$$

Similarly, the predicted historical catch rate index is calculated as:

Eq 34 $$\hat{CR}_t = e^{\ln\left(q^{CR}\right)} B_{t+0.5}^{SL}$$

where the scaling coefficient $\ln\left(q^{CR}\right)$ is an estimated parameter.

A log-normal likelihood function is used to compare predicted ($\hat{CR}_t$) and observed (I_t) biomass indices,

Eq 35 $$L\left(\hat{CR}_t \mid \theta\right) = \frac{\varpi^{CR}}{CR_t \sigma_t^{CR} \tilde{\sigma} \sqrt{2\pi}} \exp\left[\frac{-\left(\ln(CR_t) - \ln(\hat{CR}_t) + 0.5\left(\sigma_t^{CR} \tilde{\sigma} / \varpi^{CR}\right)^2\right)^2}{2\left(\sigma_t^{CR} \tilde{\sigma} / \varpi^{CR}\right)^2}\right].$$

The normalised residual is

Eq 36 $$residual = \frac{\ln(CR_t) - \ln(\hat{CR}_t) + 0.5\left(\sigma_t^{CR} \tilde{\sigma} / \varpi^{CR}\right)^2}{\left(\sigma_t^{CR} \tilde{\sigma} / \varpi^{CR}\right)}$$

The predicted pre-recruit index is calculated as:

Eq 37 $$\hat{I}_t^{PR} = e^{\ln\left(q^{PRI}\right)} \sum_{g} \sum_{s<l_g} N_{s,t+0.5}^{g} V_{s,k,z}^{g}$$

where the scaling coefficient $\ln\left(q^{PRI}\right)$ is an estimated parameter.

A log-normal likelihood function is used to compare predicted ($\hat{I}_t^{PR}$) and observed (I_t^{PR}) biomass indices,

Eq 38 $$L\left(\hat{I}_t^{PR} \mid \theta\right) = \frac{\varpi^{PRI}}{I_t^{PR} \sigma_t^{PRI} \tilde{\sigma} \sqrt{2\pi}} \exp\left[\frac{-\left(\ln(I_t^{PR}) - \ln(\hat{I}_t^{PR}) + 0.5\left(\sigma_t^{PRI} \tilde{\sigma} / \varpi^{PRI}\right)^2\right)^2}{2\left(\sigma_t^{PRI} \tilde{\sigma} / \varpi^{PRI}\right)^2}\right].$$

The normalised residual is

Eq 39

$$residual = \frac{\ln(I_t^{PR}) - \ln(\hat{I}_t^{PR}) + 0.5\left(\sigma_t^{PRI}\tilde{\sigma} / \varpi^{PRI}\right)^2}{\left(\sigma_t^{PRI}\tilde{\sigma} / \varpi^{PRI}\right)}$$

A.12 Predictions and likelihood for proportion-at-size

The observed relative proportions-at-size $p^g_{s,t}$ for each sex category are fitted for each period. In each period, these proportions sum to one across the three sex categories. The model predictions for the relative proportions-at-size in each category are:

Eq 40

$$\hat{p}^g_{s,t} = \frac{V^g_{s,k,z} N^g_{s,t+0.5}}{\sum_g \sum_s V^g_{s,k,z} N^g_{s,t+0.5}}$$

We use the normal likelihood proposed by Bentley (Breen et al. 2002) for fitting the model predictions to the observed proportions-at-size:

Eq 41

$$L(\hat{p}^g_{s,t} \mid \theta) = \frac{\kappa_t \varpi^p \sqrt{\left(p^g_{s,t} + 0.1\right)}}{\tilde{\sigma}\sqrt{2\pi}} \exp\left(\frac{-\left(p^g_{s,t} + 0.1\right)\left(\hat{p}^g_{s,t} - p^g_{s,t}\right)^2}{2\left(\tilde{\sigma} / \kappa_t \varpi^p\right)^2} \right)$$

where ϖ^p is the relative weight applied to the proportion-at-size data.

The relative weight κ_t is calculated for each sample from a six-month period, t. Each sample comprises measurements from the various months with the period and various statistical areas within the larger area being assessed (CRA 4 or CRA 5). If m indexes month and o indexes statistical area, the proportion of lobsters in sex g at size s, aggregated within the area x month cell, $p^g_{m,o,s}$, can be expressed as

Eq 42

$$p^g_{m,o,s} = n^g_{m,o,s} \Big/ \sum_g \sum_s n^g_{m,o,s}$$

The weight given to this cell, $c_{m,o}$, is a function of the cube root of the number measured, the cube root of the number of days sampled, $D_{m,o}$, and the proportion of the total catch in period t taken in that month x area cell:

Eq 43

$$c_{m,o} = \frac{\sqrt[3]{\sum_g \sum_s n^g_{m,o,s}} \sqrt[3]{D_{m,o}}\, C_{m,o}}{\sum_m \sum_o C_{m,o}}$$

The proportion of lobsters at size and sex in the whole sample for period t is:

Eq 44

$$p^g_{s,t} = \frac{c_{m,o} p^g_{m,o,s}}{\sum_m \sum_o \sum_s \sum_g \left(c_{m,o} p^g_{m,o,s}\right)}$$

and the effective sample size is then the sum of the cell weights:

Eq 45 $$\kappa_t = \sum_m \sum_o c_{m,o}.$$

To prevent individual datasets from having functionally either most of the weight or no weight in the model fitting, we truncated κ_t values greater than 10 to 10, and less than 1 to 1.

The normalised residual for a proportion-at-length is:

Eq 46 $$residual = \frac{\sqrt{p_{s,t}^g + 0.1}\left(\hat{p}_{s,t}^g - p_{s,t}^g\right)}{\left(\tilde{\sigma} / \kappa_t \varpi^p\right)}$$

A.13 Likelihood of tag size increments

The predicted size of a recaptured tagged lobster is calculated by simulating each moult during the time at liberty. For the first moult the predicted size after moulting, $\hat{S}_i^{g,recap}$, is

Eq 47 $$\hat{S}_i^{g,recap} = \left[\frac{{S_i^{g,tag}}^{h^g}}{x^g} + y^g\left(1 - \frac{1}{x^g}\right)\right]^{\left(1/h^g\right)}$$

If the animal was at liberty for more than one moulting period for that sex, then the resulting size is calculated as above, replacing $S_{i,j}^{g,tag}$ with the result of Eq 47, and so on.

A normal likelihood function is used to compare predicted and observed sizes at recapture:

Eq 48 $$L\left(\hat{S}_i^{g,recap} \mid \theta\right) = \frac{1}{\sqrt{2\pi}\varphi_i^g} \exp\left(-\frac{\left(S_i^{g,recap} - \hat{S}_i^{g,recap}\right)^2}{2\left(\varphi_i^g\right)^2}\right)$$

where the standard deviation φ_i^g is calculated as follows. For a single moult, the standard deviation is the determined from the c.v. and the expected increment:

Eq 49

$$\varphi_{s,1}^g = \left(\left(y^g + h^g\ S_i^{g,tag}\right)CV^g - \varphi^{d,\min}\right)\left(\frac{1}{\pi} \times \tan^{-1}\left(\left(\left(y^g + h^g\ S_i^{g,tag}\right)CV^g - \varphi^{d,\min}\right) \times 10^6\right) + 0.5\right) + \varphi^{d,\min}$$

This differentiable function constrains the $\varphi_{s,1}^g$ to be equal to or greater than $\varphi^{d,\min}$. For more than one moult,

Eq 50 $$\left(\varphi_s^g\right)^2 = \sum_j \left(\varphi_{s,j}^g\right)^2 + \left(\sigma^{d,obs}\tilde{\sigma} / \varpi^{TAG}\right)^2$$

where

Eq 51

$$\varphi_{s,j}^{g}=\left(\left(y^{g}+h^{g}\ S_{i,j}^{g,tag}\right)CV^{g}-\varphi^{d,\min}\right)\left(\frac{1}{\pi}\times\tan^{-1}\left(\left(\left(y^{g}+h^{g}\ S_{i,j}^{g,tag}\right)CV^{g}-\varphi^{d,\min}\right)\times10^{6}\right)+0.5\right)+\varphi^{d,\min}$$

where j indexes the number of moults and $\sigma^{d,obs}$ is the standard deviation of observation error.

The normalised residual is:

Eq 52 $$residual=\frac{S_i^{g,recap}-\hat{S}_i^{g,recap}}{\varphi_i^{g}}$$

A.14 Likelihood of recruitment residuals

Annual recruitment deviations, which cause recruitment to move away from average recruitment, are penalised with a normal likelihood function:

Eq 53 $$L\left(\varepsilon_i\mid\theta\right)=\frac{1}{\sigma^{\varepsilon}\sqrt{2\pi}}\exp\left[\frac{-\sum\left(\varepsilon_i\right)^2}{2\left(\sigma^{\varepsilon}\right)^2}\right]$$

A.15 Surplus production

The model calculates surplus production as catch plus the change in biomass between years:

$$P_t=B_{t+2}^{recr}-B_t^{recr}+C_t^{SL}+C_t^{NSL}+C_{t+1}^{SL}+C_{t+1}^{NSL}$$

where t indexes period.

APPENDIX B. DATA USED IN THE ASSESSMENT

Table B1: Catch data in kilograms used for the CRA 3 assessment. Catches were reported by calendar year up to 1978. From 1979 onwards, catches are reported by fishing year (1 April to 31 March).

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Export discrepancy unreported[3]	Recreational[4]	Reported commercial illegal[5]	Unreported illegal[6]	Customary[7]
1945	1	1	21243	0	4000	157	3324	4000
1945	2	2	21889	0	36000	162	3425	36000
1946	1	3	19091	0	4000	141	2987	4000
1946	2	4	19672	0	36000	146	3078	36000
1947	1	5	27123	0	4000	201	4244	4000
1947	2	6	27947	0	36000	207	4373	36000
1948	1	7	28049	0	4000	208	4389	4000
1948	2	8	28902	0	36000	214	4523	36000
1949	1	9	15789	0	4000	117	2471	4000
1949	2	10	16268	0	36000	120	2546	36000
1950	1	11	20442	0	4000	151	3199	4000
1950	2	12	21064	0	36000	156	3296	36000
1951	1	13	26748	0	4000	198	4186	4000
1951	2	14	27561	0	36000	204	4313	36000
1952	1	15	17991	0	4000	133	2815	4000
1952	2	16	18537	0	36000	137	2901	36000
1953	1	17	17315	0	4000	128	2709	4000
1953	2	18	17841	0	36000	132	2792	36000
1954	1	19	10259	0	4000	76	1605	4000
1954	2	20	10571	0	36000	78	1654	36000
1955	1	21	7782	0	4000	58	1218	4000
1955	2	22	8018	0	36000	59	1255	36000
1956	1	23	6581	0	4000	49	1030	4000
1956	2	24	6781	0	36000	50	1061	36000
1957	1	25	11059	0	4000	82	1731	4000
1957	2	26	11396	0	36000	84	1783	36000
1958	1	27	13336	0	4000	99	2087	4000
1958	2	28	13742	0	36000	102	2150	36000
1959	1	29	14337	0	4000	106	2243	4000
1959	2	30	14773	0	36000	109	2312	36000
1960	1	31	17140	0	4000	127	2682	4000
1960	2	32	17661	0	36000	131	2764	36000
1961	1	33	28149	0	4000	208	4405	4000
1961	2	34	29005	0	36000	215	4539	36000
1962	1	35	31527	0	4000	233	4933	4000
1962	2	36	32485	0	36000	240	5083	36000
1963	1	37	43508	0	4000	322	6808	4000
1963	2	38	73557	0	36000	545	11510	36000
1964	1	39	134291	0	4000	994	21014	4000
1964	2	40	77885	0	36000	577	12187	36000
1965	1	41	89026	0	4000	659	13931	4000
1965	2	42	97639	0	36000	723	15279	36000

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Export discrepancy unreported[3]	Recreational[4]	Reported commercial illegal[5]	Unreported illegal[6]	Customary[7]
1966	1	43	115684	0	4000	856	18102	4000
1966	2	44	121101	0	36000	896	18950	36000
1967	1	45	135897	0	4000	1006	21265	4000
1967	2	46	213541	0	36000	1581	33415	36000
1968	1	47	183895	0	4000	1361	28776	4000
1968	2	48	179154	0	36000	1326	28034	36000
1969	1	49	138754	0	4000	1027	21712	4000
1969	2	50	122096	0	36000	904	19106	36000
1970	1	51	80643	0	4000	597	12619	4000
1970	2	52	125507	0	36000	929	19639	36000
1971	1	53	56698	0	4000	420	8872	4000
1971	2	54	90178	0	36000	668	14111	36000
1972	1	55	47800	0	4000	354	7480	4000
1972	2	56	83928	0	36000	621	13133	36000
1973	1	57	31577	0	4000	234	4941	4000
1973	2	58	71394	0	36000	528	11172	36000
1974	1	59	56119	8817	4000	334	7056	4000
1974	2	60	126881	19445	36000	755	15953	36000
1975	1	61	49679	14027	4000	560	11833	4000
1975	2	62	112321	30936	36000	1266	26755	36000
1976	1	63	60719	13827	4000	547	11573	4000
1976	2	64	137281	30494	36000	1238	26165	36000
1977	1	65	67465	19880	4000	805	17023	4000
1977	2	66	152535	43844	36000	1821	38487	36000
1978	1	67	93651	23254	4000	1110	23468	4000
1978	2	68	211738	51285	36000	2510	53060	36000
1979	1	69	106225	10392	4000	416	8804	4000
1979	2	70	374037	36376	36000	1467	31002	36000
1980	1	71	155565	16945	4000	801	16942	4000
1980	2	72	450776	49147	36000	2322	49092	36000
1981	1	73	153865	0	4000	1139	24077	4000
1981	2	74	420205	0	36000	3111	65754	36000
1982	1	75	184819	0	4000	1368	28921	4000
1982	2	76	549080	0	36000	4065	85920	36000
1983	1	77	246870	0	4000	1827	38630	4000
1983	2	78	516835	0	36000	3826	80875	36000
1984	1	79	194596	0	4000	1440	30450	4000
1984	2	80	514334	0	36000	3807	80483	36000
1985	1	81	152684	0	4000	1130	23892	4000
1985	2	82	501393	0	36000	3712	78458	36000
1986	1	83	100623	0	4000	745	15746	4000
1986	2	84	469356	0	36000	3474	73445	36000
1987	1	85	85236	0	4000	631	13338	4000
1987	2	86	270185	0	36000	2000	42279	36000
1988	1	87	54052	0	4000	400	8458	4000
1988	2	88	227738	0	36000	1686	35637	36000
1989	1	89	81011	0	4000	600	12677	4000
1989	2	90	304859	0	36000	2257	47704	36000

Fishing year	Season[1]	Sequential season number	Commercial reported[2]	Export discrepancy unreported[3]	Recreational[4]	Reported commercial illegal[5]	Unreported illegal[6]	Customary[7]
1990	1	91	81533	0	4000	3275	69238	4000
1990	2	92	242580	0	36000	9745	206000	36000
1991	1	93	63307	0	4000	2863	60522	4000
1991	2	94	205489	0	36000	9293	196451	36000
1992	1	95	41551	0	4000	2450	51791	4000
1992	2	96	149960	0	36000	8842	186917	36000
1993	1	97	120507	0	4000	4428	93608	4000
1993	2	98	58958	0	36000	2167	45798	36000
1994	1	99	146167	0	4000	1726	36480	4000
1994	2	100	14516	0	36000	171	3623	36000
1995	1	101	150438	0	4000	2729	57686	4000
1995	2	102	6437	0	36000	117	2468	36000
1996	1	103	200983	0	4000	3746	79196	4000
1996	2	104	2563	0	36000	48	1010	36000
1997	1	105	222120	0	4000	2874	60759	4000
1997	2	106	1281	0	36000	17	350	36000
1998	1	107	292265	0	4000	3668	77540	4000
1998	2	108	33441	0	36000	420	8872	36000
1999	1	109	286901	0	4000	5405	114259	4000
1999	2	110	39165	0	36000	738	15598	36000
2000	1	111	258549	0	4000	2777	58692	4000
2000	2	112	69533	0	36000	747	15784	36000
2001	1	113	182198	0	4000	2129	45011	4000
2001	2	114	107676	0	36000	1258	26601	36000
2002	1	115	164004	0	4000	1907	40320	4000
2002	2	116	127283	0	36000	1480	31292	36000
2003	1	117	120638	0	4000	2260	47783	4000
2003	2	118	95118	0	36000	1782	37675	36000

[1] 1=autumn/winter (AW) season; 2=spring/summer (SS) season

[2] These are the total reported commercial catches from catch statistics. Seasonal splits are calculated as reported in Section 3.3.1.1. These are added to the SL catch category.

[3] The estimates for unreported export discrepancies are calculated from a comparison of total reported commercial catch with published export statistics (Breen 1991). The appropriate seasonal splits and size limits are applied to this category.

[4] Recreational catch is added to the SL catch category and a 10%:90% (autumn/winter – spring/summer) seasonal split is used.

[5] This is the fraction of illegal catch which is thought by the Ministry of Fisheries Compliance Unit to have been processed through normal legal channels. This value is subtracted from the total reported commercial catch when calculating the total legal catch in order to avoid double counting of catch. This value has only been estimated in the most recent years (1996) and this fraction has been applied retrospectively to the period of illegal catch estimates.

[6] This is the remaining fraction of illegal catch which is thought to have been processed through other channels by the Ministry of Fisheries Compliance Unit. This catch is added to the NSL catch. The total illegal catch is the sum of these two illegal components.

[7] Customary catches are added to the NSL catch category and a 10%:90% (autumn/winter – spring/summer) seasonal split is used.

Table B2: Data input file for the CRA 3 assessment: year, period, SL and NSL catches (t), CPUE indices and their associated standard errors, historical catch rate (CR) indices, pre-recruit (PRI) indices, male and female size limits (MLS), selectivity epochs and sequential recruitment deviation (Rdev) indices.

Year	Per.	SL catch	NSL catch	CPUE indices[1]	S. E. CPUE indices[2]	CR indices[3]	PRI indices[4]	Male MLS	Female MLS	Sel. epoch	Rdev
1945	1	23.09	27.07	0	0	0	0	0	0	1	1
1945	2	39.73	0	0	0	0	0	0	0	1	1
1946	3	20.95	26.35	0	0	0	0	0	0	1	2
1946	4	37.53	0	0	0	0	0	0	0	1	2
1947	5	28.92	29.03	0	0	0	0	0	0	1	3
1947	6	45.74	0	0	0	0	0	0	0	1	3
1948	7	29.84	29.33	0	0	0	0	0	0	1	4
1948	8	46.69	0	0	0	0	0	0	0	1	4
1949	9	17.67	25.25	0	0	0	0	0	0	1	5
1949	10	34.15	0	0	0	0	0	0	0	1	5
1950	11	22.29	5.35	0	0	0	0	47	49	1	6
1950	12	38.91	21.45	0	0	0	0	47	49	1	6
1951	13	28.55	6.38	0	0	0	0	47	49	1	7
1951	14	45.36	22.52	0	0	0	0	47	49	1	7
1952	15	19.86	4.95	0	0	0	0	51	53	1	8
1952	16	36.4	21.04	0	0	0	0	51	53	1	8
1953	17	19.19	4.84	0	0	0	0	51	53	1	9
1953	18	35.71	20.92	0	0	0	0	51	53	1	9
1954	19	12.18	3.68	0	0	0	0	51	53	1	10
1954	20	28.49	19.73	0	0	0	0	51	53	1	10
1955	21	9.72	3.28	0	0	0	0	51	53	1	11
1955	22	25.96	19.31	0	0	0	0	51	53	1	11
1956	23	8.53	3.08	0	0	0	0	51	53	1	12
1956	24	24.73	19.11	0	0	0	0	51	53	1	12
1957	25	12.98	3.81	0	0	0	0	51	53	1	13
1957	26	29.31	19.87	0	0	0	0	51	53	1	13
1958	27	15.24	4.19	0	0	0	0	51	53	1	14
1958	28	31.64	20.25	0	0	0	0	51	53	1	14
1959	29	16.23	4.35	0	0	0	0	53	58	1	15
1959	30	32.66	20.42	0	0	0	0	53	58	1	15
1960	31	19.01	4.81	0	0	0	0	53	58	1	16
1960	32	35.53	20.89	0	0	0	0	53	58	1	16
1961	33	29.94	6.61	0	0	0	0	53	58	1	17
1961	34	46.79	22.75	0	0	0	0	53	58	1	17
1962	35	33.29	7.17	0	0	0	0	53	58	1	18
1962	36	50.24	23.32	0	0	0	0	53	58	1	18
1963	37	45.19	9.13	0	0	92.09	0	53	58	1	19
1963	38	91.01	30.05	0	0	112.38	0	53	58	1	19
1964	39	135.3	24.01	0	0	137.23	0	53	58	1	20
1964	40	95.31	30.76	0	0	66.53	0	53	58	1	20
1965	41	90.37	16.59	0	0	87.7	0	53	58	1	21
1965	42	114.92	34	0	0	65.32	0	53	58	1	21
1966	43	116.83	20.96	0	0	69.76	0	53	58	1	22
1966	44	138.2	37.85	0	0	56.4	0	53	58	1	22

Year	Per.	SL catch	NSL catch	CPUE indices[1]	S. E. CPUE indices[2]	CR indices[3]	PRI indices[4]	Male MLS	Female MLS	Sel. epoch	Rdev
1967	45	136.89	24.27	0	0	76.04	0	53	58	1	23
1967	46	229.96	53	0	0	65.41	0	53	58	1	23
1968	47	184.53	32.14	0	0	49.12	0	53	58	1	24
1968	48	195.83	47.36	0	0	42.44	0	53	58	1	24
1969	49	139.73	24.74	0	0	45.54	0	53	58	1	25
1969	50	139.19	38.01	0	0	36.48	0	53	58	1	25
1970	51	82.05	15.22	0	0	36.81	0	53	58	1	26
1970	52	142.58	38.57	0	0	38.64	0	53	58	1	26
1971	53	58.28	11.29	0	0	31.68	0	53	58	1	27
1971	54	107.51	32.78	0	0	32.07	0	53	58	1	27
1972	55	49.45	9.83	0	0	31.59	0	53	58	1	28
1972	56	101.31	31.75	0	0	31.82	0	53	58	1	28
1973	57	33.34	7.17	0	0	33.4	0	53	58	1	29
1973	58	88.87	29.7	0	0	0	0	53	58	1	29
1974	59	57.79	9.39	0	0	0	0	53	58	1	30
1974	60	144.13	34.71	0	0	0	0	53	58	1	30
1975	61	51.12	14.39	0	0	0	0	53	58	1	31
1975	62	129.06	46.02	0	0	0	0	53	58	1	31
1976	63	62.17	14.12	0	0	0	0	53	58	1	32
1976	64	154.04	45.4	0	0	0	0	53	58	1	32
1977	65	68.66	19.83	0	0	0	0	53	58	1	33
1977	66	168.71	58.31	0	0	0	0	53	58	1	33
1978	67	94.54	26.58	0	0	0	0	53	58	1	34
1978	68	227.23	73.57	0	0	0	0	53	58	1	34
1979	69	107.81	11.22	0.853	0.038	0	0	53	58	1	35
1979	70	390.57	50.47	1.179	0.029	0	0	53	58	1	35
1980	71	156.76	19.74	0.99	0.036	0	0	53	58	1	36
1980	72	466.45	69.41	1.272	0.028	0	0	53	58	1	36
1981	73	154.73	27.22	0.947	0.036	0	0	53	58	1	37
1981	74	435.09	86.86	1.282	0.029	0	0	53	58	1	37
1982	75	185.45	32.29	1.086	0.034	0	0	53	58	1	38
1982	76	563.02	107.98	1.333	0.029	0	0	53	58	1	38
1983	77	247.04	42.46	0.981	0.033	0	0	53	58	1	39
1983	78	531.01	102.7	1.218	0.028	0	0	53	58	1	39
1984	79	195.16	33.89	0.743	0.032	0	0	53	58	1	40
1984	80	528.53	102.29	1.037	0.028	0	0	53	58	1	40
1985	81	153.55	27.02	0.661	0.032	0	0	53	58	1	41
1985	82	515.68	100.17	1.046	0.029	0	0	53	58	1	41
1986	83	101.88	18.49	0.564	0.037	0	0	53	58	1	42
1986	84	483.88	94.92	0.908	0.03	0	0	53	58	1	42
1987	85	86.61	15.97	0.438	0.034	0	0	53	58	1	43
1987	86	286.18	62.28	0.611	0.03	0	0	53	58	1	43
1988	87	55.65	10.86	0.42	0.041	0	0	54	58	1	44
1988	88	244.05	55.32	0.655	0.033	0	0	54	58	1	44
1989	89	82.41	15.28	0.416	0.038	0	0	54	58	1	45
1989	90	320.6	67.96	0.744	0.03	0	0	54	58	1	45
1990	91	80.26	74.51	0.441	0.037	0	0	54	58	1	46
1990	92	250.83	233.75	0.641	0.032	0	0	54	58	1	46

Year	Per.	SL catch	NSL catch	CPUE indices[1]	S. E. CPUE indices[2]	CR indices[3]	PRI indices[4]	Male MLS	Female MLS	Sel. epoch	Rdev
1991	93	62.44	65.39	0.293	0.036	0	0	54	58	1	47
1991	94	214.2	223.74	0.456	0.031	0	0	54	58	1	47
1992	95	41.1	56.24	0.221	0.035	0	0	54	60	1	48
1992	96	159.12	213.76	0.422	0.032	0	0	54	60	1	48
1993	97	118.08	100.04	0.455	0.039	0	1.01	52	100	2	49
1993	98	74.79	65.96	1.144	0.067	0	1.039	54	60	2	49
1994	99	146.44	40.21	0.979	0.048	0	0.973	52	100	2	50
1994	100	32.34	21.79	1.369	0.111	0	1.319	54	60	2	50
1995	101	149.71	62.41	1.534	0.052	0	1.005	52	100	2	51
1995	102	24.32	20.59	1.803	0.137	0	0	54	60	2	51
1996	103	199.24	84.94	1.989	0.052	0	1.106	52	100	2	52
1996	104	20.52	19.06	3.119	0.177	0	0	54	60	2	52
1997	105	221.25	65.63	2.826	0.054	0	0.994	52	100	2	53
1997	106	19.26	18.37	3.994	0.217	0	0	54	60	2	53
1998	107	290.6	83.21	2.054	0.051	0	0.787	52	100	2	54
1998	108	51.02	27.29	4.041	0.126	0	1.05	54	60	2	54
1999	109	283.5	121.66	2.014	0.051	0	0.845	52	100	2	55
1999	110	56.43	34.34	2.844	0.101	0	1.097	54	60	2	55
2000	111	257.77	63.47	1.43	0.047	0	0.685	52	100	2	56
2000	112	86.79	34.53	2.326	0.084	0	1.25	54	60	2	56
2001	113	182.07	49.14	1.095	0.05	0	0.763	52	100	2	56
2001	114	124.42	45.86	1.739	0.068	0	0.905	54	60	2	56
2002	115	164.1	44.23	0.788	0.046	0	0.979	52	100	2	56
2002	116	143.8	50.77	1.056	0.047	0	0.964	54	60	2	56
2003	117	120.38	52.04	0.697	0.047	0	1.187	52	100	2	56
2003	118	111.34	57.46	0.728	0.047	0	1.322	54	60	2	56

[1] These are normalised standardised CPUE indices and not scaled to units of kg per potlift

[2] Standard error of the CPUE estimates for each period

[3] Unstandardised CR indices in kg per day from Annala & King (1983)

[4] Annual standardised pre-recruit indices